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DATA BASE FOR INFLUENT HEAVY METALS IN PUBLICLY OWNED TREATMENT WORKS

by

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16. ABSTRACT

Results are presented of a 2-year study involving the identification and assembly of a data base existing within the Publicly Owned Treatment Works (POTW) of the U.S. on influent heavy metals. The general character of the data base with respect to associated descriptors (among which are % industrial contribution, % combined sewers, % infiltration/inflow, sample frequency, sample type, analytical method) is provided. Wastewater treatment plant laboratories were evaluated in the conduct of the study and generally found to be satisfactory within the framework of the evaluation method. Of the 80,000 individual pieces of data from 239 wastewater treatment plants, a substantial data base was generated for cadmium, chromium, copper, nickel, lead and zinc. Extensive data (but reduced in total volume) were obtained for silver, arsenic and mercury. Limited data were obtained for beryllium, cobalt, antimony and selenium. Aluminum, iron and manganese data were received as well. Median and mean (computed in varying manner) are reported and compared. Generally, log normal distributions were observed for all but the data extremes. While no associations could be demonstrated between the median or mean values for the composite data base and the individual descriptors using Pearson and Spearman techniques, isolation of the low percent industrial waste category from the parent data base did show significant differences for 6 of 7 metals. Lead was the metal not showing a difference.

17. KEY WORDS AND DOCUMENT ANALYSIS

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

Reported here are the results of a survey of influent heavy metals data available from municipal wastewater treatment plants. A significant sample of that data base was obtained, put in computer format on magnetic tape and characterized directly and with respect to a number of discriptors.

Francis T. Mayo, Director Municipal
Environmental Research Laboratory

ABSTRACT

Results are presented of a 2 year study involving the identification and assembly of a data base existing within the Publicly Owned Treatment Works (POTW) of the U.S. on influent heavy metals. The general character of the data base with respect to associated descriptors (among which are % industrial contribution, % combined sewers, % infiltration/inflow, sample frequency, sample type, analytical method) is provided. Wastewater treatment plant laboratories were evaluated in the conduct of the study and generally found to be satisfactory within the framework of the evaluation method. Of the 80,000 individual pieces of data from 239 wastewater treatment plants, a substantial data base was generated for cadmium, chromium, copper, nickel, lead and zinc. Extensive data (but reduced in total volume) were obtained for silver, arsenic and mercury. Limited data were obtained for beryllium, cobalt, antimony and selenium. Aluminum, iron and manganese data were received as well. Median and mean (computed in varying manner) are reported and compared. Generally, log normal distributions were observed for all but the data extremes. While no associations could be demonstrated between the median or mean values for the composite data base and the individual descriptors using Pearson and Spearman techniques, isolation of the low percent industrial waste category from the parent data base did show significant differences for 6 of 7 metals. Lead was the metal not showing a difference.

Additional data treatment procedures have been applied to illustrate future directions to be pursued with the data which have been computerized and supplied on tape with documentation to MERL Cincinnati.

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SECTION 1

INTRODUCTION

Pretreatment standards for industrial discharges have received increasing attention (1) for two reasons. First there has been a continuing focus on industrial contributions to municipal waste treatment systems (2-7). And second, concern exists over the ability of municipalities to meet NPDES effluent criteria. The heavy metals loading to publicly owned treatment works (POTWs) is of interest because of (a) the possible inhibitory effect it has on the biological treatment process, (b) the effluent levels that can be achieved as a function of influent concentration, and (c) the practice of land disposal of waste sludge where the total metal load to the treatment plant is of concern (9-12).

Though a number of general studies (4,6,8) and detailed investigations (2,3,5,7,13) have been conducted, one study (4) indicated that the existing published literature base is inadequate for making a general assessment of the relative importance of industrial, domestic, and urban nonpoint contributions to the total heavy metals load to municipal treatment systems. In reporting on the performance of POTWs (including metal removal efficiencies), another study (1) indicated that the data, which were gathered from a variety of sources, were not intended to serve as a substitute for detailed influent and effluent sampling. Though 269 plants were surveyed overall, removal data, and hence influent metals concentrations, were obtained for only 56 to 156 plants, depending upon the individual metal. What is not clear from this report and others (6) is the extent of the individual components of the existing data base for influent metals concentrations. That is to say, how many treatment plants actually measure heavy metals in their influent, which metals are measured, and with what frequency? Furthermore, no index of the quality of the data base has been attempted. Detailed accounts such as the Buffalo (3) and Kokomo (13) studies should provide a high level of analytical control and extensive information on influent metals concentrations, but replication of such studies at a number of cities would be quite expensive. An alternative to this approach is to examine the unpublished and unconsolidated data base existing in municipal records.

A study was undertaken by the University of Tennessee to determine the extent and character of this data base, specifically with respect to the influent concentrations of heavy metals. This study was conducted in two phases and had the following specific objectives:

1. To determine the extent and character of the national data base for publicly owned treatment works (POTW) influent metals concentrations.

2. To provide an indication of the quality of the data base via direct laboratory evaluation.
3. To obtain and computerize a representative sampling of the defined data base in conjunction with an array of descriptors for the data source.
4. To summarize the quantitative character of the data base and examine variations relative to the array of descriptors obtained.

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PHASE I

The first phase of the research project was to determine the extent of the influent POTW heavy metals data base on a national scale by conducting a survey. The EPA Pretreatment Guidelines (1) noted that Regional EPA offices afforded little or no direct assistance in determining which cities might have influent metals data. A similar experience was recorded in this study from an attempt to verify the existence of metals data from a specific city (knowledge of which was obtained in advance) by visiting a regional office. However, visits to each regional office afforded a rapid means of obtaining individual state contacts. These state contacts were in turn variable in their value toward completing the survey.

In most cases, considerable information was obtained as to cities that might be performing heavy metals analyses on treatment plant influents and the names of city contacts were provided. (For a few states, such as North Carolina, state agency requirements for POTW under certain circumstances included reporting of influent heavy metals.) Some states, on the other hand, had no direct knowledge of such activities within the municipal sector and were convinced that such data did not exist.

Though communication with EPA and state agency offices yielded a sizeable number of cities to be contacted, it was apparent that many cities had been excluded from the list. The criterion for the balance of the city selection process was set on the basis of population (as reported in the 1977 Rand McNally Road Atlas), as all cities of population greater than 25,000 were included. Some allowance was made for states with few cities of this size by adjusting the population cutoff to include major population centers.

The information as to whether or not the POTW measured heavy metals in the plant influent was acquired by direct telephone inquiry. In all, 900 cities were contacted, of which about 180 were contributors to other cities. (Based on the Rand McNally data, this represented a total population of 84,197,837 or 41.4% of the U.S. population.) Specifically, when the appropriate individual had been contacted (which frequently necessitated several calls and transfers) a yes/no answer regarding influent heavy metals measurements was requested. Given an affirmative response, further information was requested that consisted of a list of the metals analyzed, the frequency of measurement, the sampling procedure, the analytical method used, whether total or soluble metals or both were determined, the type of treatment, and a rough indication of how much industrial waste was included in the plant flow.

PHASE II

The second phase of the research was to obtain actual data from all cities willing to provide it. Because of variations in the amount of data available from each city and physical limitations in the anticipated computer coding of the data, requests for data were based on the frequency of analysis, as follows:

Frequency of Analysis	Data Requested
≧ 50/yr	1 year
> 10 but < 50	2 years
≦ 10/yr	4 years or what was available

In conjunction with this phase of the project, a means of evaluating the laboratories was devised, and a significant percentage of the cities supplying data were visited and their laboratory facilities and procedures were rated.

Computer formating and entry of the data were undertaken, resulting in generation of a master computer file of data and other descriptors of the data base, including the laboratory rating scores. Cities are coded by number to maintain anonymity (to some extent), but general geographic location and population data are contained in the computer data base.

The following report provides the data base characteristics and an examination of relationships to specific descriptors or lack thereof.

SECTION 2

CONCLUSIONS

1. A composite picture of the data base on heavy metals concentrations in influents to POTWs has been obtained. A significant finding in this work, outside of the data obtained, is that the information received from initial telephone contact differed considerably from that received from followup inquiry by mail. Then, data were requested from those plants responding to the mail inquiry and the real picture obtained upon receipt of data was again different.

2. Visits to 85 of the 145 cities supplying data for 239 waste treatment plants (58.6% of the cities) provided a representative selection of the laboratories supplying the data collected. The performance of these laboratories on evaluation of their facilities generated a picture of satisfactory or better performance, which lends a high degree of confidence to the reliability of the assembled data base. Most laboratories had modern equipment (principally atomic absorption instrumentation for metals analyses), and well trained personnel, and most gave special attention to representative sampling procedures.

3. Of the information assembled in computer storage, those metals with sufficient data to provide adequate characterization are cadmium, chromium (total), copper, iron, mercury, manganese, nickel, lead, and zinc. Arsenic and silver constitute an intermediate class and the balance of measured metals occurred too infrequently or were measured at too few plants to enable meaningful use of the data for general characterization.

4. Except for some seasonal effects, use of the descriptors selected to delineate causes of varied metals concentrations is not fruitful when using a lumped data base. Detailed descriptor values matched with time--corresponding metals data would be required as a minimum. Such data can be obtained to match up with the metals data in file, but this step was beyond the scope and resources of the project. For cities with more than one treatment plant, even more detailed information may be necessary to determine a reasonable relationship between metals concentrations and descriptors.

5. Though no association could be determined between the level of industrial contribution and metals concentration in POTW influents, sufficient data were available to determine baseline values for cadmium, chromium, copper, mercury, nickel, and zinc using data for cities with less than 4% industrial contribution. Only lead concentration was not significantly different for the two populations.

6. Since all of the cities that acquired influent heavy metals data also maintain similar (if not more detailed) surveillance on their effluent streams, and since the analytical data are generally of quality equal to many research labs, a detailed analysis should be made of the composite data at considerable cost reduction compared with independent sampling studies. Comparison with the results of the surveys of 25 and 40 cities being conducted for USEPA would yield a basis for comparison and validation. By including effluent data in the same data base certain predictive relationships for processes and removal efficiencies could be determined as well as relating overall effluent concentrations to influent values and treatment process.

SECTION 3

RECOMMENDATIONS

Use should be made of the assembled data base by following up for more detailed time series information on weather conditions, industrial profiles, and other descriptors for cities with the larger data bases. Under these conditions, better associations might well be elucidated. Application of multivariant statistical procedures should be made.

Though anonymity was maintained, few of the cities requested this status, and followup studies would likely be welcomed. This avenue should be pursued in light of the two major studies in progress--the 25 and 40 cities studies. This study has shown that a reliable data base is already in existence of sufficient magnitude and quality to be used for research purposes. The acquisition and computer formating of the data is a major undertaking, but the effort should serve to validate the selected efforts of past and current research. A selected number of cities, not duplicating the "detailed" cities studies representatives, should be examined independently for comparison. In addition, the 25 and 40 city studies should be compared for those cities that also appear in the data set completed in this project.

SECTION 4

LABORATORY ASSESSMENT METHODOLOGY AND RESULTS

A. Lab Quality Scoring

One of the major goals associated with the assemblage of a heavy metals data base was to assess the reliability of the data that were collected. There are three basic ways to assess the reliability of data that were collected from any given city. First, each city's treatment plant laboratory personnel could have been tested by a series of unknown samples to determine directly the ability of the staff to measure metal concentrations given the equipment on hand. This type of direct assessment method is costly and not within the scope of this project. A second related method would be to collect samples from these plants and measure those samples in a central laboratory and then compare results with the treatment plant lab technicians' findings. This is also very expensive and requires far more resources than were allocated to this project. A third approach could be to visit each laboratory where the metals measurements were made and to rate the laboratories based upon a number of criteria which were thought to affect the overall reliability of the metals measurements that were reported. This method is an indirect approach because no direct comparisons or testings are made. It is reasonable to assume that laboratories that meet the overall standards set up in the indirect method are generating reliable data and that laboratories that fail to meet the overall standards set up in the indirect method are generating data with questionable reliability. This can be true only when the overall standards include only features that are determinants in the laboratories' ability to make accurate metals measurements. This third method was selected for use in assessing the quality of the metals data base. This indirect method is described in greater detail in the next section. Although the indirect method is an adequate way of assessing any group of data generated from a laboratory, it must be pointed out that such an approach should be tested by examining a reasonable sample of cities by a direct assessment approach. In this way the less expensive indirect assessment procedure can be turned to the degree that it performs well for the purpose for which it is used. However, it has been shown that in many cases an indirect measurement approach can be of use to the degree of being fairly reliable (14). Although a thorough assessment of the indirect laboratory rating method was beyond the scope of this work, it is conceivable that future research may be directed towards testing and refining the laboratory rating method given below.

The method used to rate treatment plant laboratories in making metals measurements is based in part on the procedure developed for EPA for evaluating environmental monitoring laboratories--this procedure is well-documented and laid out in a simple evaluation manual (15). The evaluation process is based on facilities, methods used, instrumentation, existence of quality control programs, personnel which are scored based on rating criteria which reflect the opinions of the report contractor and EPA personnel.

The six part evaluation procedure for laboratory evaluation of environmental monitoring laboratories is given in Appendix A. This procedure was modified by dropping some of the general criteria, modifying certain others by making them more specific to metals measurement assessment, and simplifying others for the purposes of evaluating laboratories making metal measurements.

The original six part evaluation procedure was composed of fifty-four criteria. Table 1 gives a summary of the six part procedure. Each part is composed of one or more questions where one of three responses is to be checked by the evaluator according to the statement that best fits the laboratory being evaluated. Some of the questions are considered critical if the most applicable response identifies a problem which casts doubt on the validity of laboratory measurements being performed. These critical responses are identified with an asterisk in the original evaluation procedure given in Appendix A. The three responses to each question are also labeled with a score of 1, 3, or 5. For each of the criteria the most applicable response is then translated into a score. The average score for each part is weighted by the percentage given in Table 1. From this a total tentative score is determined. The responses that were labeled as critical are considered problems that must be resolved before a final score is assessed.

The procedure developed for evaluating the validity of metals measurements was based on taking all but eight of the original criteria. Of the remaining criteria, seven were modified to reflect the narrower goal of evaluating only the ability of a laboratory in making metals measurements. Of the criteria in the original evaluating procedure which were kept, a number had critical responses. These critical responses are flagged in the new procedure in the same manner as in the original method except no attempt in the evaluating process was made to resolve any problems identified by these critical responses. The procedure developed for metals measurement evaluations (MME) is given in Appendix B.

The criteria which make up the MME procedure were grouped into three parts: (1) Personnel and External and Internal Controls, (2) Laboratory Space and Facilities and (3) General Information about the laboratory. The first two parts were used while interviewing laboratory personnel and inspecting the facilities and the third section was used after the visit. All analyses were kept confidential and the scores have been used only for the purpose of characterizing the data set. Table 2 gives the relationship between the EPA Laboratory Evaluation Procedure for Environmental Monitoring Laboratories (15) and MME procedure developed for this research.

TABLE 1
GENERAL FORM OF EPA LABORATORY EVALUATION PROCEDURE

Part	Title	Number of Criteria	Number of Critical Criteria[†]	Overall Weight of Section
I	General Information	5	5	20%
II	Score for Personnel	6	2	20%
III	Score for Laboratory Space and Facilities	14	6	10%
IV	Score for Analytical Methods	3	1	10%
V	Score for Instruments	3	1	10%
VI	Score for Internal and External Controls	21	7	30%

[†] Number of critical criteria represents the number of specific criteria in a section that must be answered to an acceptable level in order for the laboratory to obtain an overall acceptable score.

TABLE 2
RELATIONSHIP EPA LABORATORY EVALUATION PROCEDURE AND THE METALS MEASUREMENT EVALUATION PROCEDURE

Part		Status	New Section and Number
PART I			
Question 1.	Appropriateness of Organization*	E	-- --
Question 2.	Impairment of Functions*	E	-- --
Question 3.	Strength of Management*	E	-- --
Question 4.	Objectivity of Laboratory*	S	III-1
Question 5.	Cooperation Obtained*	S	III-2
PART II			
Question 1.	Supervisor Training	S	I-1
Question 2.	Supervisor Experience*	S	I-2
Question 3.	Job Descriptions	E	-- --
Question 4.	Training Program	S	I-3
Question 5.	Turnover Rate*	M	I-4
Question 6.	General Morale	M	III-3
PART III			
Question 1.	General Characteristics of Space and Facilities	E	-- --
Question 2.	Office Space	E	-- --
Question 3.	Laboratory Space*	M	II-1
Question 4.	Bench-top Space	M	II-2
Question 5.	Hood Space and Operation	M	II-3
Question 6.	Storage Space - Chemicals	S	II-4
Question 7.	Sample Storage Space*	S	II-5
Question 8.	Controlled Space*	M	II-9
Question 9.	Library	S	II-7
Question 10.	Safety Equipment/Procedures*	E	-- --
Question 11.	Distilled/Deionized Water*	M	II-8
Question 12.	Glassware Supply and Washing*	S	II-12
Question 13.	Housekeeping	S	III-6
Question 14.	Data Processing Equipment and Logistic Services	E	-- --
PART IV			
Question 1.	Reference Methods or Approved Alternates*	S	III-7
Question 2.	Reagent and Media Preparation	S	III-8
Question 3.	Performance According to Standard	S	I-9

TABLE 2 (Con't)

PART		STATUS	NEW SECTION AND NUMBER
PART V			
Question 1.	Required Instrumentation*	S	III-9
Question 2.	Function Tests and Standardization of Instruments	S	I-5
Question 3.	Calibration Equipment	S	I-6
PART VI			
Question 1.	Responsibility for Calibration	S	I-7
Question 2.	Adequacy of Calibration Logs	S	I-8
Question 3.	Adequacy of Calibration and Maintenance Practices*	S	III-10
Question 4.	Sampling Plans and Sampling Equipment	S	I-10
Question 5.	Sample Collection and Preservation	S	I-11
Question 6.	Identification and Storage of Samples*	S	II-6
Question 7.	Laboratory Handling of Samples	S	II-10
Question 8.	Chain of Custody*	S	I-12
Question 9.	Field Control of Sampling	S	I-13
Question 10.	Control of Monitoring Activities	S	I-14
Question 11.	Clarity of QC Policy	S	I-15
Question 12.	Written Program/Manual*	S	I-16
Question 13.	Responsibility for Quality*	S	I-17
Question 14.	Training in QC	S	I-18
Question 15.	Control of Chemicals and Reagents	S	I-19
Question 16.	Internal Checks: Precision and Accuracy	S	I-20
Question 17.	Internal Checks: Routine Duplicates, Blanks, Spikes*	S	I-21
Question 18.	Statistical Methods	S	I-22
Question 19.	Inter-lab Proficiency Tests*	S	I-23
Question 20.	Record System	S	III-11
Question 21.	Report System	S	III-12

E - eliminated
S - same
M - modified
* - indicates possible critical response

B. Laboratory Scoring

The format of the EPA evaluation procedure (15) consists of six sets of scoring items, where each item may be given 1, 3, or 5 points. The subscore for each set is then accumulated as the set normalized-weighted sum of the item point count:

$$SS_j = \left[\sum_{i=1}^{n_j} I_{ij} W_{ij} / 5\sum_{i=1}^{n_j} W_{ij} \right] W_j$$

Where

SS_j is the subscore of the jth scoring set

W_j is the maximum subscore of the jth scoring set

I_{ij} is the point count of the ith item in the jth scoring set, $I_{ij}=(1,3,5)$

W_{ij} is the weight of the ith item in the jth scoring set, $W_{ij}=(1,2,4)$

n_j is the number of items in the jth scoring set.

The items that have an asterisk associated with a point count of one indicate a critical decision item that must be resolved before the final score is calculated. The subscore function then is:

$$SS_j = \left[\sum_{i=1}^{n_j} I_{ij} W_{ij} / \sum_{i=1}^{n_j} W_{ij} \right] W_j \prod_{i=1}^{n_j} d_{ij}$$

Where

d_{ij} = the decision item in the jth scoring set, where $d_{ij} = 1$ if $I_{ij} \neq 1$, or if i is not an asterisked item and $d_{ij} = 0$ if $I_{ij} = 1$ and i is an asterisked item. The laboratory score is the unweighted sum of the subscores, where a score of 60 represents the minimum passing score.

Care was taken to preserve the weighting structure from the original method such that a score of 60 in the MME method has the same meaning as in the EPA manual, and each item preserved its individual weight in the score.

The lab quality score for the MME was calculated by:

$$LQS = \sum_{i=1}^{6} \sum_{i=1}^{n_j} \left[\left(\frac{\sum_{i=1}^{6} W_j}{\sum_{i=1}^{6} W'_j} \right) W'_j \left(\frac{\sum_{i=j}^{n_j} I'_{ij} W'_{ij}}{5\sum_{i=1}^{n_j} W'_{ij}} \right) \right]$$

Where $W' = \frac{W_j}{\sum_{i=1}^{n_j} w_{ij}} \sum_{i=1}^{n_j} w'_{ij}$

W'_{ij} = the weights used in the edited manual

n_j = the number of items in the edited jth scoring set. In terms of the rearranged MME rating form, the above equation was transformed to:

$$LQS = \sum_{k=1}^{6} \left[\sum_{j=1}^{3} \sum_{i=1}^{n_j} w_{ij} \, w(k_{ij}) I_{ij} / \sum_{j=1}^{3} \sum_{i=1}^{n_j} w_{ij} \right]$$

Where

$$w(K_{ij}) = W'_j / 5 \quad \frac{\sum_{j=1}^{6} W_j}{\sum_{j=1}^{6} W'_j}$$

and k_{ij} is the unedited scoring set associated with the ith item in the jth group in the edited manual.

The items marked with an asterisk in the unedited manual were similarly marked for this application, but it was not clear that every such item should constitute a disqualification (or a score of zero). Therefore, the LQS was calculated and reported along with the number of asterisk items.

The Lab Quality Scores are clearly not cardinal numbers and are not definitely ordinal other than the division of scores at a value of 60. For the purposes of this project, it was considered sufficient to categorize facilities into three groups:

1) A LQS greater than 60 with no more than 1 asterisked item

2) A LQS greater than 60 with more than 1 asterisked item

3) A Laboratory not visited where no LQS can be calculated.

Table 3 gives a compilation of Laboratory Quality Scores for the cities that were visited. Of the eighty-five cities, fifty-three of them had scores above 60 and did not have any critical responses. This indicates that the majority of laboratories have adequate facilities, personnel, and training for heavy metals measurement.

TABLE 3. RANGE IN FACILITIES' LQI SCORES

Number of Critical Questions Missed	Range in LQS					
	50-59	60-69	70-79	80-89	90-100	Total
0		3	16	22	12	53
1		2	3	5		10
2		4	3			7
3		4	2			6
4		3	1			4
>5	3	2				5
Total	3	18	25	27	12	85

Cities with LQI scores	85
Cities not visited	60
Grand Total	145

SECTION 5

DATA BASE CHARACTERISTICS

A. Telephone Survey Versus Data Received

The initial phase of the research was to determine which cities did in fact possess data on raw sewage metal concentrations at the treatment plant inlet. While some information was obtained from Regional EPA and State agency officials, most of the information obtained was by direct telephone contact with individual cities. In addition to cities and contact names provided by EPA and State agencies, an arbitrary population limit of 25,000 was set and all cities with this population or greater were listed. In total, 900 cities were selected for contact. Based on 1970 Rand McNally data, these cities represented a total population of 84,197,837 or roughly 41% of the United States population.

Affirmative responses to the question of whether or not heavy metals were assayed in the plant influent were followed up with a simple mail form that contained the information recorded from the telephone contact. The cities were asked to verify the information recorded. From the telephone survey, 444 cities gave indication of influent metals data. Of these, 287 operated their own POTW and 157 contributed to regional plants. The mail follow up of these responses generated a slightly different picture. Now 262 cities (representing 347 individual treatment plants) indicated influent heavy metals data were obtained. When actual requests were made for data in phase II of the project, it was determined that 88 cities that had reported influent data were available, measured metals only in the plant effluent. Ultimately, data were received from 145 cities representing 239 individual treatment plants. Sixteen additional cities promised data but did not send it even after repeated telephone follow ups.

B. Phase II Data Base

Table 4 presents the distribution of plants supplying data by EPA region. Clearly, the data base is dominated by regions III, IV, V and IX. Nine states did not supply data. These were Alaska, Idaho, Maine, Nebraska, New Mexico, North Dakota, South Dakota, West Virginia and Wyoming. Of these, only South Dakota reportedly had one city with data (which were not sent).

States which had large numbers of plants with data were as follows:

California	32 plants
New York	18 plants
North Carolina	15 plants
Tennessee	14 plants
Indiana	13 plants
Illinois	11 plants
Virginia	11 plants
Pennsylvania	10 plants
Massachusetts	10 plants

TABLE 4. NUMBER OF TREATMENT PLANTS SUPPLYING DATA BY EPA REGION

EPA Region	Number of Plants
I	15
II	24
III	32
IV	40
V	48
VI	17
VII	15
VIII	8
IX	37
X	3
	239

Contrasted with an earlier study by Burns and Roe[7] this data base represented 41 states compared with only 20 by the earlier study which had its data base heavily concentrated in Connecticut, Kentucky, New Jersey, Pennsylvania and Wisconsin. On the other hand, the earlier study represented 269 individual treatment plants and thus likely had greater representation from cities with a population of less than 25,000.

Descriptors

Information was sought in conjunction with the data supplied regarding the nature of the sample taken, frequency of sampling (implicit in data supplied), type of analytical procedures used, and whether or not analysis was done in-house. Furthermore, plants were requested to supply information regarding industrial contribution to the influent (both on a % flow and % of BOD basis) and the sewer system characteristics. The latter consisted of estimates of percent of combined sewers (nearest 10%), percent of flow attributable to stormwater (nearest 10%) and the magnitude of infiltration and inflow (3 categories only, <25%, 25 to 100%, >100%). Tables 5 to 12 summarize these descriptors in terms of the number of treatment plants in each for the particular descriptor for each of the individual metals for which data have been supplied.

The first observation from these data is that the dominant metals measured are cadmium, chromium (total), copper, nickel, lead and zinc, all with over 200 plants measuring. Silver, arsenic, iron, mercury and manganese represent an intermediate group with aluminum, cobalt and selenium showing much lower numbers of plant measuring. The balance of the results represented in the overall data base are measured by so few plants that one cannot say that a useful data base exists.

The dominant treatment plant type making influent measurements is an activated sludge plant (Table 5). For those 6 elements measured by large numbers of treatment plants, weekly sampling generally is most common with monthly sampling a close second followed, again closely, by daily sampling (Table 6). For silver, arsenic, mercury, and selenium, most of those plants measuring did so monthly and, to a lesser extent, quarterly. By far, the greatest number of plants made measurements on a 24 hour composite sample although a significant number failed to report sample type (Table 7). Seven day and 30 day composite samples would correspond to weekly and monthly sampling frequencies while 24 hour composite samples could also apply to those sampling frequencies. Of importance is that the majority of samples are composites and flow proportioning was the most common practice.

By far, the dominant analysis method was atomic absorption spectrophotometry as is illustrated in Table 8. Plant visits confirmed this observation. When wet chemistry or Hach kit measurements were employed, they were generally used for relatively few metals, most commonly copper and chromium.

Most of the data represent analyses conducted by analysts at the treatment plant or a central municipal laboratory rather than by commercial laboratories (Table 9).

TABLE 5. DISTRIBUTION OF TREATMENT PLANT TYPES FOR INDIVIDUAL METAL MEASURES

	Number of Plants Treatment Plant Types					
Metal	Primary Treatment	Trickling Filter	Activated Sludge	Physical/ Chemical	Other	Unknown
Ag	9	11	28	3	4	21
Al	4	1	25	3	0	6
As	10	8	22	4	2	22
B	2	1	5	0	0	2
Ba	0	4	7	0	2	9
Be	2	0	2	1	0	4
Ca	0	1	2	0	0	0
Cd	22	21	104	5	7	39
Co	2	3	23	2	3	5
Cr	22	23	117	6	7	43
Cr(III)	0	0	3	0	1	0
Cr(VI)	1	1	5	1	1	5
Cu	25	25	123	6	7	41
Fe	10	14	80	5	5	28
Hg	17	11	50	4	3	29
K	0	0	1	0	0	0
Mg	0	1	2	0	0	1
Mn	5	10	38	3	3	20
Mo	0	0	3	2	0	4
Ni	21	23	104	6	7	34
Pb	21	18	100	5	6	41
Sb	0	0	7	2	0	2
Se	1	5	11	1	2	19
Si	0	0	13	0	0	7
Sr	0	0	1	0	0	0
Ti	0	0	1	0	0	1
Tl	0	0	2	0	0	1
V	2	0	2	0	0	2
Zn	24	24	119	6	7	40

TABLE 6. DISTRIBUTION OF SAMPLING FREQUENCY FOR INDIVIDUAL METALS MEASURED

Metal	Number of Plants Frequency of Sampling and Analysis Daily	Weekly	Bi-Weekly	Monthly	Quarterly	Semi-Annual	Annual	Infr
Ag	6	10	2	36	11	6	1	4
Al	6	3	0	11	12	1	4	2
As	5	3	3	32	10	6	4	5
B	1	0	1	1	2	1	3	1
Ba	2	2	1	12	2	1	1	1
Be	2	1	0	2	3	0	1	0
Ca	1	0	1	0	0	1	0	0
Cd	39	51	7	47	25	8	6	15
Co	6	10	4	10	1	2	3	2
Cr	39	60	9	52	25	9	6	18
Cr(III)	0	0	1	0	0	3	0	0
Cr(VI)	4	1	2	4	0	3	0	0
Cu	46	62	10	46	27	11	7	18
Fe	26	42	2	37	14	5	8	8
Hg	15	22	4	32	16	8	4	13
K	1	0	0	0	0	0	0	0
Mg	3	0	0	0	0	0	0	1
Mn	10	12	2	31	11	4	5	4
Mo	0	0	0	3	3	0	2	1
Ni	36	54	5	50	26	9	5	10
Pb	31	49	6	47	25	11	5	17
Sb	2	2	0	3	1	1	1	1
Se	3	3	2	18	8	2	1	2
Si	0	11	0	4	2	0	2	1
Sr	1	0	0	0	0	0	0	0
Ti	0	0	0	0	2	0	0	0
Tl	0	0	0	1	2	0	0	0
V	2	0	0	3	1	0	0	0
Zn	43	60	7	49	26	11	6	18

TABLE 7. DISTRIBUTION OF SAMPLE TYPES FOR INDIVIDUAL METALS MEASURED

	Number of Plants Sample Type					
Metal	24 hr. Composite	Composite Unspecified	7 day Composite	30 day Composite	Grab	Unknown
Ag	47	2	0	2	1	24
Al	28	0	1	0	4	6
As	45	2	0	2	4	15
B	5	0	0	0	2	3
Ba	14	0	0	0	1	7
Be	7	0	1	0	0	1
Ca	2	1	0	0	0	0
Cd	123	7	3	13	10	42
Co	22	0	2	0	5	9
Cr	135	8	3	13	10	49
Cr(III)	3	0	0	0	0	1
Cr(IV)	7	0	0	0	0	7
Cu	145	7	3	14	10	48
Fe	94	7	2	11	4	24
Hg	70	2	1	13	5	23
K	1	0	0	0	0	0
Mg	2	1	0	0	1	0
Mn	50	2	3	2	3	19
Mo	7	0	0	0	1	1
Ni	122	8	3	14	6	42
Pb	117	8	3	14	7	42
Sb	7	0	0	0	1	3
Se	26	0	0	2	2	9
Si	3	0	0	11	1	5
Sr	1	0	0	0	0	0
Ti	1	0	0	0	0	1
Tl	2	0	0	0	0	0
V	6	0	0	0	0	0
Zn	139	8	3	14	8	48

TABLE 8. DISTRIBUTION OF ANALYSIS METHOD BY INDIVIDUAL METALS

	Number of Cities Method of Measurement				
Metal	Atomic Absorption	Wet Chemistry	Hach Kit	Other	Unknown
Ag	65	1	1	2	8
Al	35	0	0	3	1
As	55	7	0	0	6
B	6	1	0	1	2
Ba	18	3	0	0	1
Be	9	0	0	0	0
Ca	2	1	0	0	0
Cd	182	0	0	3	13
Co	20	0	4	2	3
Cr	188	6	5	4	15
Cr(III)	1	1	2	0	0
Cr(VI)	8	3	2	0	1
Cu	198	2	7	4	16
Fe	128	4	4	3	3
Hg	101	0	0	2	11
K	1	0	0	0	0
Mg	3	0	0	0	1
Mn	72	2	0	1	4
Mo	8	0	0	0	1
Ni	178	1	1	3	12
Pb	167	3	3	4	14
Sb	10	0	0	0	1
Se	34	4	0	0	1
Si	15	4	0	0	1
Sr	1	0	0	0	0
Ti	2	0	0	0	0
Tl	3	0	0	0	0
V	6	0	0	0	0
Zn	191	3	5	3	18

TABLE 9. WHERE ANALYSES WERE CONDUCTED BY INDIVIDUAL METAL

Metal	Number of Plants	
	Outside Lab Analysis	Internal Analysis
Ag	15	61
Al	6	33
As	11	57
B	5	5
Ba	5	17
Be	4	5
Ca	1	2
Cd	20	178
Co	8	30
Cr	22	196
Cr(III)	2	2
Cr(IV)	2	12
Cu	23	204
Fe	13	129
Hg	14	100
K	0	1
Mg	2	2
Mn	10	69
Mo	4	5
Ni	21	174
Pb	20	171
Sb	2	9
Se	8	31
Si	2	18
Sr	0	1
Ti	1	1
Tl	1	2
V	0	6
Zn	22	198

The distribution of plants by industrial flow contribution (Table 10) presents a reasonable spread with appreciable representation in the 0 to 4% category. For those metals measured by a large number of treatment plants the 10 to 19% and 20 to 39% categories dominate. Relatively few treatment plants handle greater than 60% industrial waste as might be expected. These data do not differentiate with respect to industrial type although in many cases information was supplied regarding dominant industrial contributions. This issue will be of significance in examining metals concentration in relation to industrial flow. Tables 11 and 12 show distributions of plants with respect to combined sewers and infiltration and inflow, respectively. Each of these factors relates to effects that climatological variations may have on influent metals concentrations and these effects may work opposite to other influences with subsequent obliteration of apparent relationships between metal concentrations and system descriptors. For most metals categories, roughly half of the plants measuring a given metal reported zero percent combined sewers. The balance of the remaining plants were distributed among the other three (arbitrary) ranges but predominantly in the 61 to 100% category.

Laboratory Quality Index

Of the 145 cities represented by the 239 treatment plants, 85 (59%) were visited (representing 140 treatment plants) and their laboratories evaluated using a modification of a procedure contained in an EPA report, "Evaluation of Environmental Monitoring Laboratories".[15] Calculation of the lab quality index (LQI) has been described previously in Chapter IV and the complete rating form used is presented in Appendix B. Default items contained in the original documents' rating scheme and which were carried over to the modified form, were counted for each laboratory but not used directly to discount the validity of any laboratory's data. Furthermore, the absolute LQI cannot be directly assigned meaning as to the competence level of the laboratory. The original evaluation procedure set a score of 60 as the minimum passing score. This significance was maintained in the modified procedure used and consequently, scores below 60 clearly indicate reason to question the reliability. On the contrary, an LQI of 90 does not necessarily indicate a proportionally greater confidence in the data reliability versus an LQI of 80.

The distribution of LQI values by EPA region is presented in Table 13 in terms of treatment plants represented by a particular LQI. All but 3 plants (which also represent 3 different cities/laboratories) achieved a passing score based on the criterion established. For the most part, the LQI values would imply that the data base is of acceptable analytical reliability.

Table 14 contains a summary of information that was received from 239 treatment plants and entered into the computer. Data supplied were usually in the form of copies of laboratory records and contain entries for zero concentrations or less than a particular value. For some metals, the combination of less than or zero values was high. Notably, arsenic, cadmium and selenium had 42, 41 and 44 percent of the values reported in this fashion. Zinc and copper on the other hand were reported mostly as discrete values with only 2 and 8 percent of the values reported as zero or less than, respectively.

TABLE 10. DISTRIBUTION OF PERCENT OF PLANT FLOW ATTRIBUTABLE TO INDUSTRIAL CONTRIBUTION FOR INDIVIDUAL METALS MEASURED

Metal	Number of Plants Percent of Industrial Flow 0-4	5-9	10-19	20-39	40-59	60-79	80-100	Unknown
Ag	8	10	35	11	7	2	2	1
Al	9	1	11	10	6	0	2	0
As	6	11	29	10	8	2	2	0
B	1	2	1	4	2	0	0	0
Ba	1	0	12	4	2	2	1	0
Be	1	0	3	2	2	0	1	0
Ca	0	0	2	1	0	0	0	0
Cd	29	25	64	44	25	6	3	2
Co	4	6	7	6	8	1	1	1
Cr	33	23	69	32	28	5	6	2
Cr(III)	0	2	2	0	0	0	0	0
Cr(VI)	0	3	6	3	2	0	0	0
Cu	34	27	73	51	28	6	6	2
Fe	21	16	43	41	16	2	2	1
Hg	18	16	50	15	11	2	2	0
K	0	0	0	1	0	0	0	0
Mg	0	0	2	1	1	0	0	0
Mn	12	8	28	21	7	1	1	1
Mo	0	1	4	3	0	0	1	0
Ni	24	21	69	42	26	6	4	3
Pb	28	23	71	37	22	5	3	2
Sb	1	0	3	5	0	0	2	0
Se	4	4	19	6	3	1	2	0
Si	2	3	11	3	0	0	1	0
Sr	0	0	0	1	0	0	0	0
Ti	0	0	0	2	0	0	0	0
Tl	0	0	0	2	0	0	1	0
V	0	1	2	1	1	0	1	0
Zn	33	25	74	48	26	7	5	2

TABLE 11. DISTRIBUTION OF PERCENT COMBINED SEWERS FOR INDIVIDUAL METALS MEASURED.

Metal	Number of Plants Percent of Combined Sewers				
	0	1-30	31-60	61-100	Unknown
Ag	46	13	5	4	8
Al	28	5	5	1	0
As	39	13	4	2	10
B	6	3	1	0	0
Ba	13	4	4	1	0
Be	2	5	0	1	1
Ca	1	1	0	1	0
Cd	104	20	28	33	13
Co	21	8	6	3	0
Cr	117	22	32	34	13
Cr(III)	2	2	0	0	0
Cr(VI)	10	2	1	1	0
Cu	122	25	32	35	13
Fe	73	12	21	27	9
Hg	52	17	16	19	10
K	0	1	0	0	0
Mg	2	1	0	1	0
Mn	48	7	10	4	10
Mo	5	4	0	0	0
Ni	98	19	29	36	13
Pb	92	23	30	34	12
Sb	9	2	0	0	0
Se	21	6	2	1	9
Si	8	1	0	11	0
Sr	0	1	0	0	0
Ti	1	1	0	0	0
Tl	2	1	0	0	0
V	1	0	2	2	1
Zn	117	25	30	35	13

TABLE 12. DISTRIBUTION OF PERCENT INFILTRATION AND INFLOW FOR INDIVIDUAL METALS MEASURED.

Metal	Number of Plants Percent Infiltration/Inflow <25	25-100	>100	Unknown
Ag	20	34	5	17
Al	10	24	2	3
As	16	33	6	13
B	3	4	2	1
Ba	7	10	2	3
Be	2	5	2	0
Ca	1	2	0	0
Cd	58	82	19	39
Co	9	16	3	10
Cr	68	86	25	39
Cr(III)	1	2	1	0
Cr(VI)	3	7	3	1
Cu	69	94	25	39
Fe	43	59	9	31
Hg	33	48	9	24
K	0	1	0	0
Mg	1	2	0	1
Mn	18	37	5	19
Mo	1	6	0	2
Ni	57	86	18	34
Pb	55	82	16	38
Sb	2	7	0	2
Se	4	22	3	10
Si	12	6	0	2
Sr	0	1	0	0
Ti	1	1	0	0
Tl	1	1	0	1
V	0	5	1	0
Zn	65	92	23	40

TABLE 13. LAB QUALITY INDEX DISTRIBUTION

LQI	Number of Treatment Plants with a Given LQI EPA Region 1	2	3	4	5	6	7	8	9	10	Total
48		1									1
53	1										1
59		1									1
---Minimum passing score---											
60				1		1				1	3
61		1									1
63				1	1						2
64									1		1
65				1	3						4
66				1			1				2
67					1			1			2
68				3							3
69				2	1		1				4
70			1			7					8
71	1				1	2					4
72			1		2						3
73							2				2
74				1							1
75			3				1				4
76			1	5							6
77		1			3						4
78	1			2					1		4
79	5				1						6
80					2			2	2		6
81			1	3							4
83					1				4		5
84					2	5			1		8
85					1		1				2
86					3	1					4
87					4						4
88		1					3		3		7
89					2				1		3
91					1		2		8		11
93					2				1		3
94					1						1
96			9		6						15
Σ	8	5	16	20	38	16	11	3	22	1	140

TABLE 14. SUMMARY OF HEAVY METALS DATA BASE FROM 239 WASTEWATER TREATMENT PLANT INFLUENTS.

	Number of Observations			Concentration, mg/l	
Metal	Observations	Number <a value	Number Zero	Maximum*	Minimum#
Ag	1,696	186	196	0.900	0.0015
Al	857	6	7	186.0	0.0017
As	1,140	222	251	1.90	0.0003
B	101	83	1	20.0	0.123
Ba	441	39	109	13.5	0.010
Be	171	103	36	0.090	0.001
Cd	8,937	1,214	2,455	2.14	0.0002
Co	323	77	17	0.900	0.0011
Cr	11,362	693	840	83.3	0.0008
Cu	12,351	243	686	36.5	0.0001
Fe	8,558	158	73	999.0	0.006
Hg	2,698	357	176	3.00	0.0001
Mn	2,302	8	26	13.2	0.008
Mo	22	17	0	0.874	0.0011
Ni	9,461	938	1,029	111.4	0.002
Pb	7,521	540	900	11.6	0.001
Sb	155	88	57	2.10	0.0003
Se	592	97	156	10.0	0.002
Sn	6	3	0	13.3	0.010
Sr	85	8	0	0.45	0.025
Ti	4	0	0	2.00	0.14
V	125	95	1	3.10	0.50
Zn	11,341	116	96	28.7	0.0001
Total	80,241	5,410	7,214		

*largest value reported for the entire data set

#smallest discrete value reported for the entire data set

The range of values for each metal presented in Table 14 may reflect individual analytical anomalies at a given municipality but were the values supplied as verified by follow up communication. Working with the data set requires some selective editing to evaluate if anomalous values are the result of infrequent or one shot grab sampling, a single outlier in the data set, interference prone analysis and/or a low LQI.

Mean and Median Concentrations

For the case where no data editing is involved, the question arises as to how one handles inordinately high values or the zero and less than values. Furthermore, should equal weight be given to plants with fewer data points (even though the request procedure attempted to normalize this variation)? In looking at mean values and attempting to compute mass flow, concern must be directed at the "zero" or less than value. Is it really zero or just below the detection limit? The data of Tables 15 and 16 examine the difference between median and mean values, the latter computed in several different ways. Table 15 refers to "weighted values" defined as follows:

$$\text{Weighted Median} = \frac{\Sigma(\text{plant median x \# of observations for plant})}{\Sigma(\text{number of observations per plant})}$$

$$\text{Weighted Mean} = \frac{\Sigma(\text{plant mean x \# of observations for plant})}{\Sigma(\text{number of observations per plant})}$$

$$= \frac{\Sigma \text{ individual values}}{\text{total \# of values}}$$

The former is actually a weighted mean of the median values while the latter is the overall mean of the composite data base. In both Tables 15 and 16 the mean values have been computed in four different ways: (1) Mean, LT=0 is computed by setting all less than values equal to zero and counting these and zero values and setting all less than values equal to that value; (2) Mean, LT=value is computed by including zero values and setting all less than values equal to that value; (3) Mean, LT,0=Detection Limit is computed by setting all zero and less than values equal to the detection limit, either as reported or determined by the computer through selection of the lowest reported discrete value; (4) Mean, Discrete Values is computed by excluding all zero and less than values.

For the data of Table 15, the median values are consistently lower than all of the means (with the exception of arsenic) although in some cases little change is noted. Because of zero values, for some plants the individual medians are reported as zero and these values depress the mean of the medians relative to the mean values. Obviously, this is the result of more than 50% of the recorded values being zero. Setting of less than values equal to zero resulted in mean values less than the median values only for arsenic, beryllium, cobalt, antimony and selenium. For each of these elements, high percentages of the total observations were reported as less than or zero (42, 81, 27, 94 and 44%, respectively). For those metals for which a large number of observations were available (Cd, Cr, Co, Cu, Hg, Ni, Pb, and Zn) the median values and the 3 mean values that considered zero and less than values in one manner or another were relatively close in magnitude (20 to 30%).

TABLE 15. COMPARISON OF MEDIAN AND MEAN VALUES (WEIGHTED) FOR THE ENTIRE DATA BASE.

Metal	#Observ	#Plants	Median*	Mean* LT=0	Mean* LT=Value	Mean* LT,0=Det.Lim.	Mean* Discrete Values
Ag	1,696	76	.017	.024	.026	.026	.032
Al	854	39	2.41	3.39	3.39	3.39	3.44
As	1,140	68	.085	.012	.069	.069	.021
Be	171	9	.0091	.0040	.0097	.0098	.0216
Cd	8,937	198	.024	.027	.030	.030	.046
Co	323	38	.053	.050	.066	.066	.070
Cr	11,362	218	.40	.45	.45	.45	.52
Cu	12,351	227	.42	.46	.46	.46	.49
Fe	8,558	142	3.18	5.13	5.13	5.13	5.27
Hg	2,698	114	.063	.11	.14	.14	.14
Mn	2,302	79	.16	.17	.17	.17	.18
Ni	9,461	195	.23	.31	.32	.32	.39
Pb	7,521	191	.12	.15	.16	.16	.18
Sb	155	11	.43	.24	.37	.37	.37
Se	592	39	.041	.038	.047	.047	.066
Zn	11,341	220	.52	.63	.63	.63	.64

*Values reported as mg/l.

TABLE 16. COMPARISON OF MEAN AND MEDIAN VALUES* (UNWEIGHTED) FOR THE ENTIRE DATA BASE.

Metal	Median	Mean LT=0	Mean LT=Value	Mean LT,0=Det.Lim.	Mean Discrete Values
Ag	.021	.028	.030	.030	.028
Al	2.98	3.70	3.72	3.72	3.70
As	.048	.035	.050	.050	.035
Be	.0069	.0025	.0072	.0076	.0025
Cd	.024	.024	.029	.030	.024
Co	.056	.035	.066	.067	.035
Cr	.39	.44	.45	.45	.44
Cu	.35	.38	.39	.39	.39
Fe	3.44	4.79	4.79	4.80	4.79
Hg	.011	.013	.019	.019	.013
Mn	.35	.37	.37	.37	.37
Ni	.26	.31	.32	.32	.31
Pb	.14	.16	.19	.19	.16
Sb	.22	.09	.22	.22	.09
Se	.31	.28	.30	.30	.28
Zn	.51	.61	.61	.61	.61

Comparison of Mean (LT=0) with Mean (LT=value) shows no significant change for chromium, copper, nickel, lead and zinc. For cadmium an 11% increase is seen and for mercury the increase is 40%. The large increase seen for arsenic and the anomalous behavior for the median versus the mean values is likely the result of unusual detection limits or less than values reported by one or more plants especially if a large fraction of the total data set comes from this source. The unweighted data smooth out this effect as will be seen below.

The mean of the discrete values reported is higher than the other values for silver, cadmium, chromium and nickel but by only 20 to 30% not orders of magnitude. For other metals, the change is less (copper, mercury, lead and zinc).

Another way of examining the data is to assume equal reliability of the means and medians for each of the individual plant data sets. Table 16 presents the data in this manner, defined as follows:

$$\text{Unweighted median} = \frac{\Sigma \text{ plant medians}}{\text{number of plants}}$$

$$\text{Unweighted mean} = \frac{\Sigma \text{ plant means}}{\text{number of plants}}$$

Unweighted median values are slightly higher for silver, cobalt, manganese, nickel, lead and selenium, while the reverse occurred for arsenic, beryllium, cadmium, chromium, copper, mercury, antimony and zinc. A similar mix of plus and minus values was observed for the various unweighted means when compared to the weighted counterparts but the differences are generally small except for mercury (unweighted values lower by roughly a factor of 10) and selenium (unweighted values higher by roughly a factor of 10). Interestingly, for the unweighted data, the change in values among the various computed means and even the median were much less than observed for the weighted values. Usually the median is less than the mean values and the Mean (LT=0) is less than the other mean values. In some cases, this difference is very small while for arsenic, beryllium, cobalt and antimony, larger changes are seen. Each of these elements has a large percentage of zero and less than values and/or is measured by relatively few treatment plants. Figure 1 contains a graphical presentation of the ranges, unweighted median and mean (LT=value) values for those heavy metals included in the priority pollutant list.

Distribution of Medians and Means

Cumulative distributions on the individual plant medians and means typically resulted in compression of most values at the axis due to dominance by 2 to 4 data points. Figures 2 and 3 illustrate this behavior for arsenic and cadmium, respectively, for individual plant median concentrations. Similar plots were obtained for each of the four means. Elimination of the top 4 values and replotting the remainder provides a better view of the data distribution as illustrated in Figures 4 and 5.

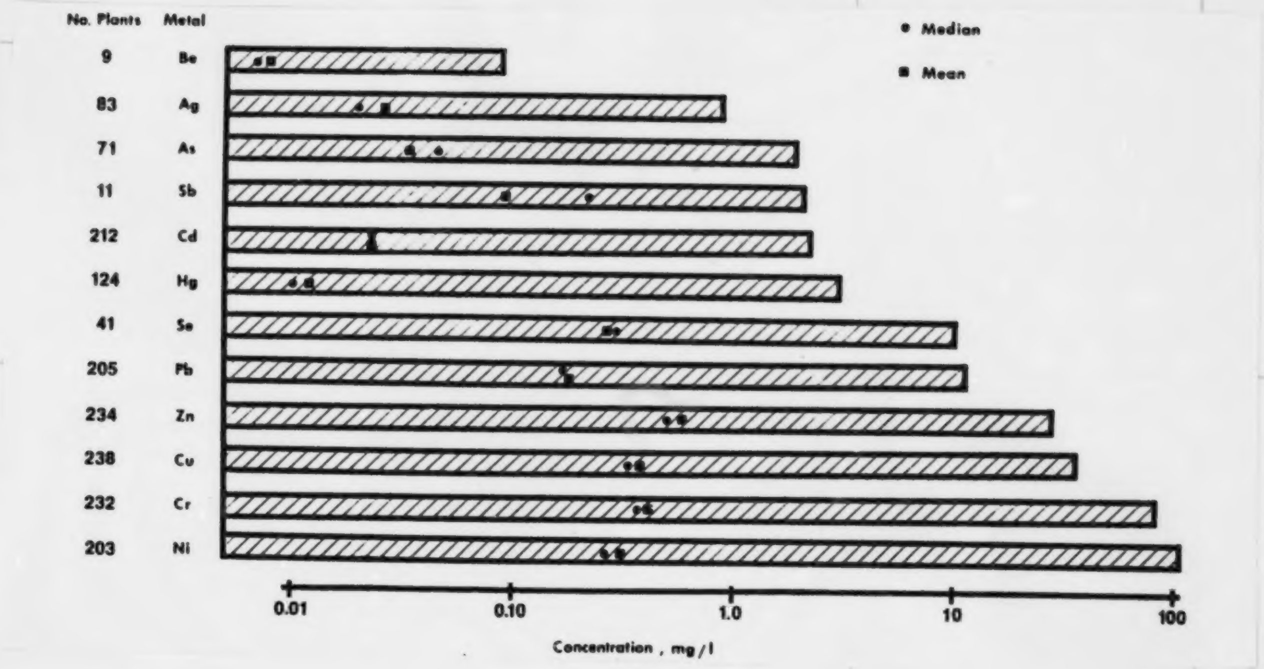

Figure 1. Range of individual concentrations reported and unweighted median and mean (LT-value) concentrations for metals on the priority pollutant list.

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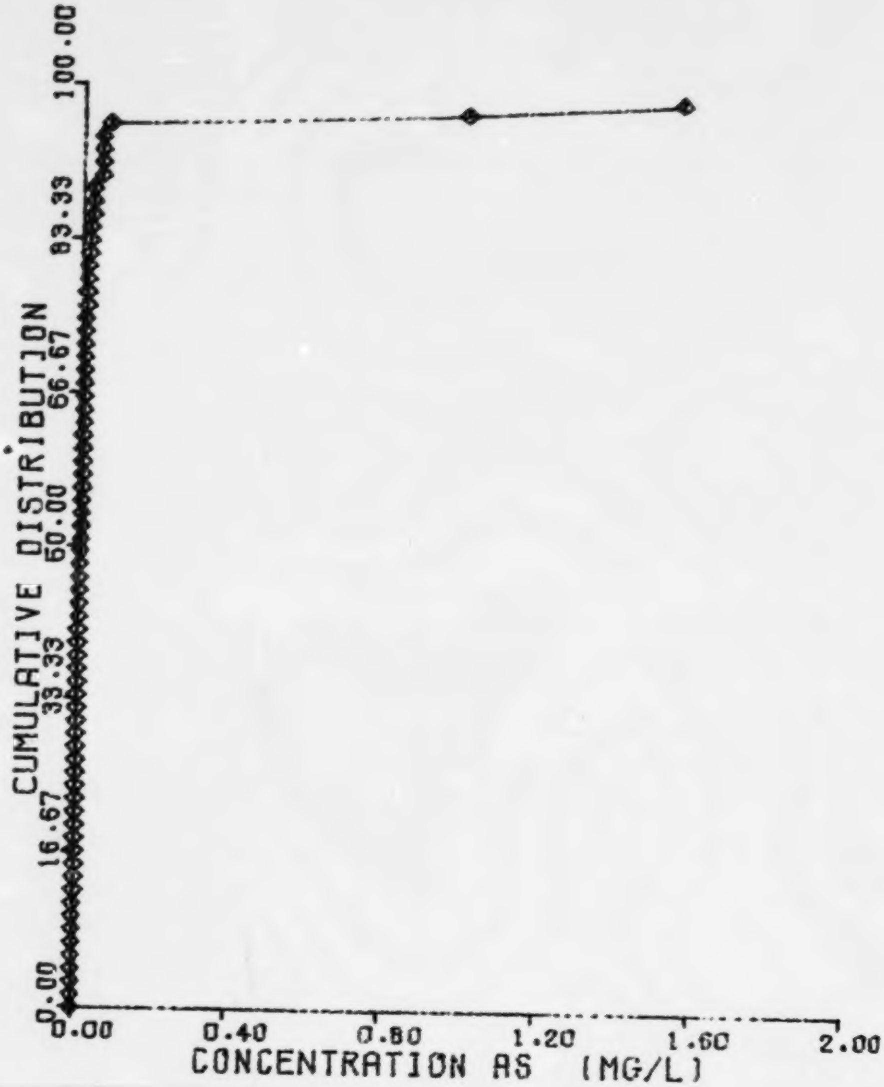

Figure 2. Cumulative distribution of individual plant median arsenic concentrations.

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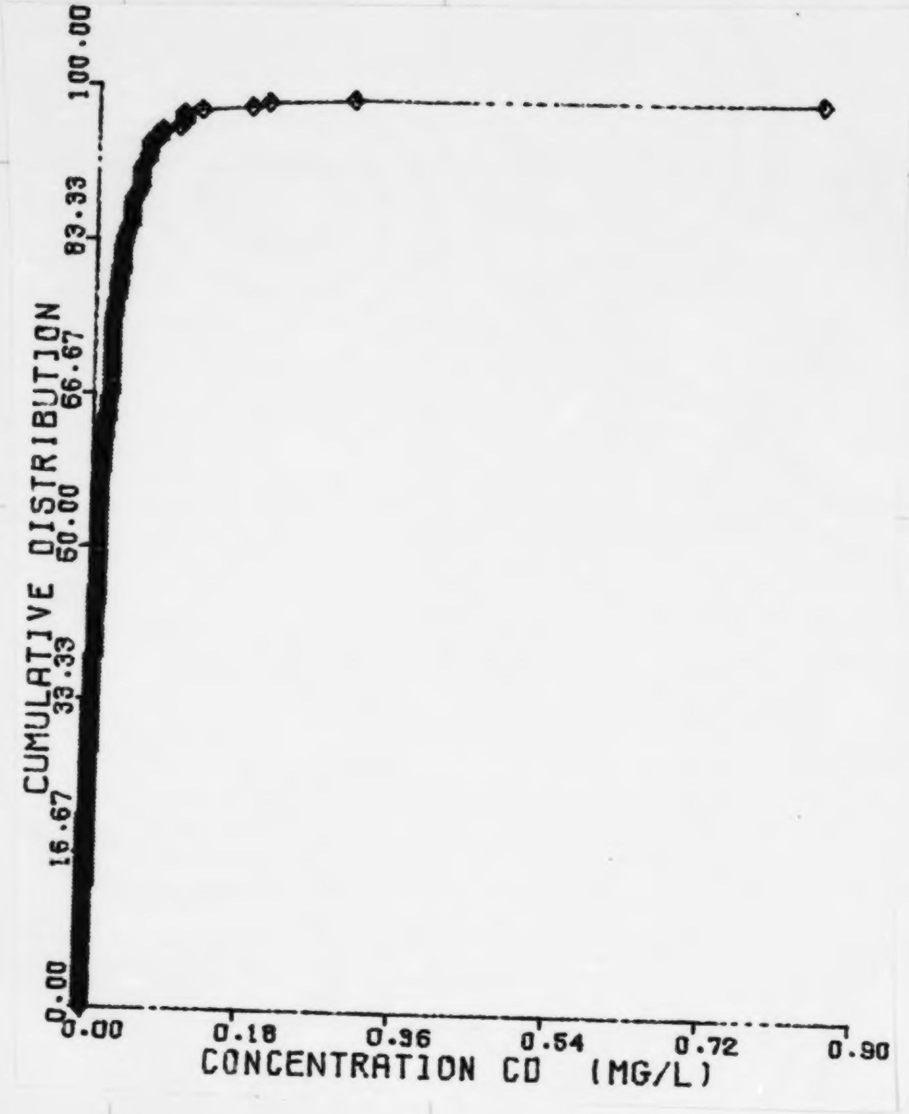

Figure 3. Cumulative distribution of individual plant median cadmium concentrations.

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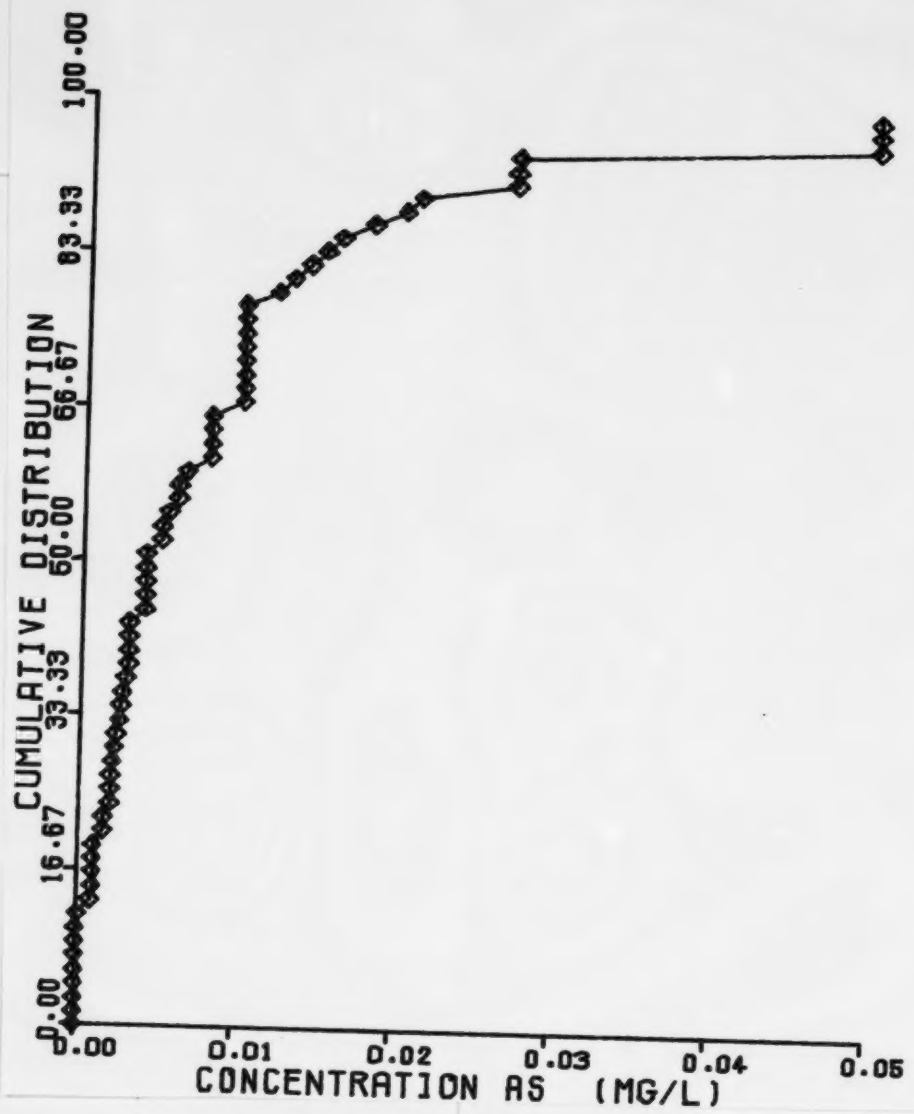

Figure 4. Cumulative distribution of individual plant median arsenic concentrations after deletion of the four highest values.

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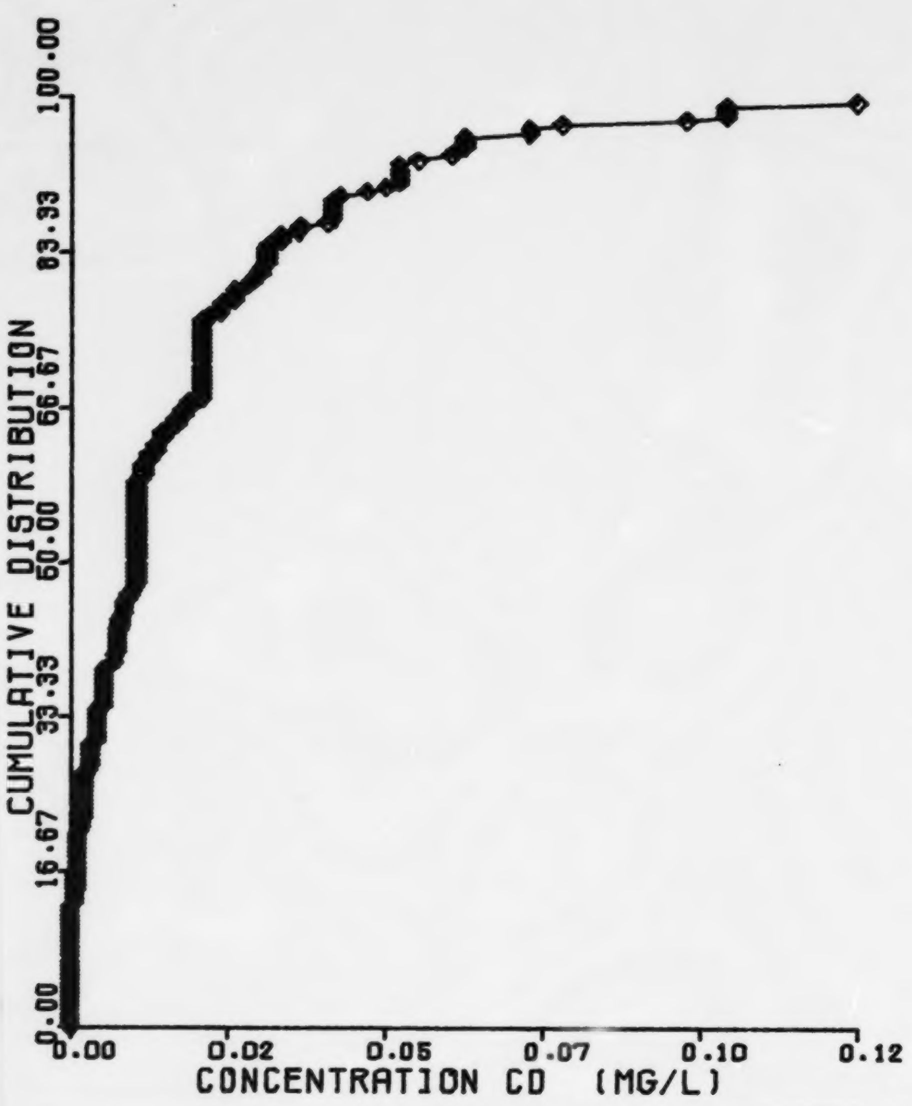

Figure 5. Cumulative distribution of individual plant median cadmium concentrations after deletion of the four highest values.

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Examination of the highest 4 values for several elements for which substantial data were available indicated a pattern associated with those values. Table 17 summarizes this pattern for 9 elements, usually those with limited observations but in several instances, a substantial data base is represented. In these cases decimal errors in coding may be suspect or analytical interferences (example plant 298-1 analyzes for chromium by wet chemical procedures rather than atomic absorption spectrophotometry) or the plant has unusual contributions to its sewer. For the chromium case, plant 298-1 also reports a 40% industrial contribution by flow.

These factors may lead to the apparent differences in median concentrations in the ten EPA regions shown in Table 18. Copper and chromium values are highly elevated in Region I relative to other parts of the country. The two highest chromium and copper values are located in Region I which has only 15 plants represented in the total data base. Silver, arsenic and mercury also show wide variation among the regions.

Overall, the metal concentration data tend to fit a log normal distribution. This is true for each of the representations for the plant mean and median values. Figures 6 through 19 demonstrate this relationship for 14 metals and metaloids of interest. The log concentration-probability plots (cumulative percentage) are for the plant median values (where non zero values were obtained) and each figure provides the 99% confidence interval boundaries. Within quite reasonable agreement, the data tend to follow a log normal distribution. This becomes important when applying statistical tests to the data base since these tests assume particular distributions of the data set behavior as a whole.

Figure 18 for Vanadium is included to illustrate the lack of sufficient data for this metal as the basis for excluding it and several others from any further data treatment.

TABLE 17. LISTING HIGHEST 4 MEDIAN AND MEAN (DISCRETE VALUES) FOR NINE ELEMENTS.

	Median Values			Discrete Value Mean		
Element	Plant #	Median mg/l	# Observ	Plant #	Mean mg/l	# Observ
Arsenic	456-1	1.56	1	456-1	1.56	1
	432-1	1.00	88 (75<)*	877-4	.48	7 (3<)*
	635-1	0.07	8	877-3	.11	8 (5<)
	4 Plants	0.005		641-1	.065	17
Cadmium	456-1	.85	1	456-1	.85	1
	577-1	.30	32 (28<)	514-1	.19	360
	359-1	.20	3	359-1	.17	3
	514-1	.18	360	295-1	.13	3 (2<)
Chromium	298-1	32.6#	31	298-1	33.3*	31
	715-5	4.9	6	715-1	4.8	12
	584-1	3.1	329	715-5	4.1	6
	643-1	2.8	6	715-3	2.9	13
Copper	58-1	26.0	1	58-1	26.0	1
	179-2	11.5	232	179-2	11.2	232
	2234-1	1.7	29	2234-1	2.4	29
	519-1	1.03	82	519-1	1.3	82
Mercury	546-1	0.60	301	546-1	1.01	301
	617-1	0.50	4 (4<)	877-1	0.23	10 (1<)
	359-1	0.028	3	359-1	0.058	3
	514-1	0.010	2	132-1	0.040	79(40=0)
Nickel	2234-1	11.3	29	2234-1	16.3	29
	359-1	9.5	3	359-1	8.6	3
	58-1	2.4	1	58-1	2.4	1
	456-1	1.5	1	215-1	1.5	234
Lead	295-3	8.5	1	295-3	8.5	1
	295-9	2.7	4	295-9	2.7	4
	491-1	1.1	3	321-1	1.2	139(134=0)
	359-1	0.72	3	491-1	1.0	3

(Continued)

TABLE 17 (Continued)

	Median Values			Discrete Value Mean		
Element	Plant #	Median mg/l	# Observ	Plant #	Mean mg/l	# Observ
Selenium	295-3	10.0	1	295-3	10.0	1
	617-1	1.0	6 (6<)	15-2	0.34	3
	15-1	.37	3	15-1	0.19	3
	15-2	.19	3	2234-1	0.15	34
Zinc	58-1	10.3	1	58-1	10.3	1
	2234-1	3.14	29	2234-1	4.88	29
	530-1	3.12	96	530-1	3.99	96
	456-1	3.10	1	456-1	3.10	1

[*] (<) indicates number of total values reported as less than a particular value.

[#] wet chemical analysis. Others atomic absorption.

TABLE 18. MEDIAN CONCENTRATION (UNWEIGHTED) BY EPA REGION

Region	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
I	0.025	0.0080	0.029	3.40	2.45	0.0023	0.52	0.29	1.19
II	0.028	0.098	0.0092	0.093	0.28	0.0010	0.54	0.075	0.52
III	0.0035	0.0017	0.0070	0.12	0.16	0.0008	0.11	0.23	0.44
IV	0.059	0.21	0.051	0.092	0.081	0.0031	0.42	0.092	0.38
V	0.0067	0.010	0.038	0.37	0.47	0.031	0.18	0.15	0.66
VI	0.0051	0.0083	0.012	0.064	0.10	0.0007	0.065	0.056	0.18
VII	0.022	0.027	0.025	0.034	0.14	0.064	0.14	0.15	0.42
VIII	0.0010	0.0010	0.013	0.081	0.19	0.0044	0.22	0.089	0.36
IX	0.020	0.0058	0.018	0.18	0.25	0.0010	0.15	0.12	0.50
X	-	-	0.014	0.10	0.21	0.0013	0.080	0.13	0.65
Composite National	0.021	0.048	0.024	0.39	0.35	0.011	0.26	0.14	0.51
Maximum/Minimum	59	210	7.3	53	30	91	8.3	3.9	6.6

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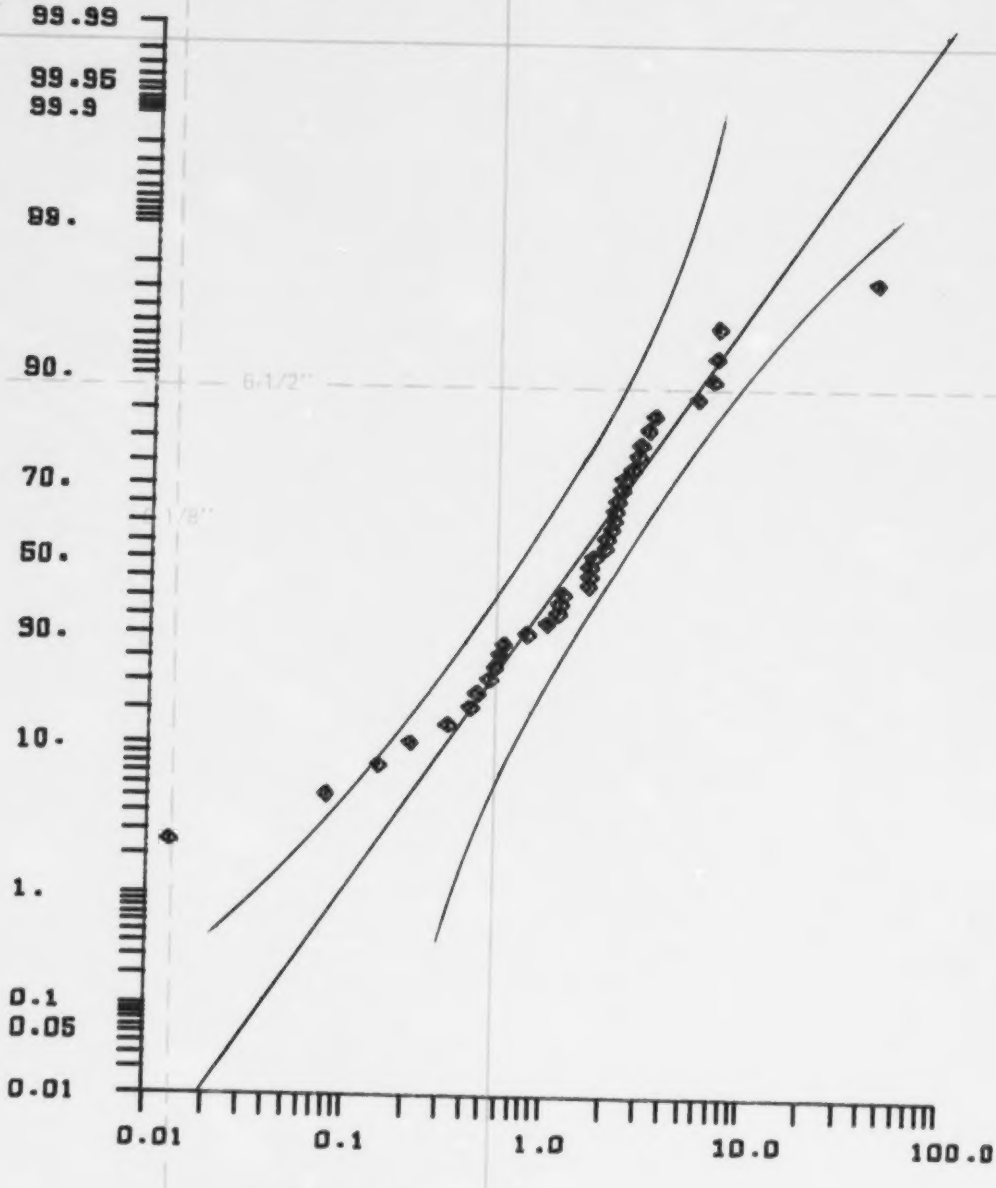

Figure 6. Log probability plot for reported median Aluminum concentrations.

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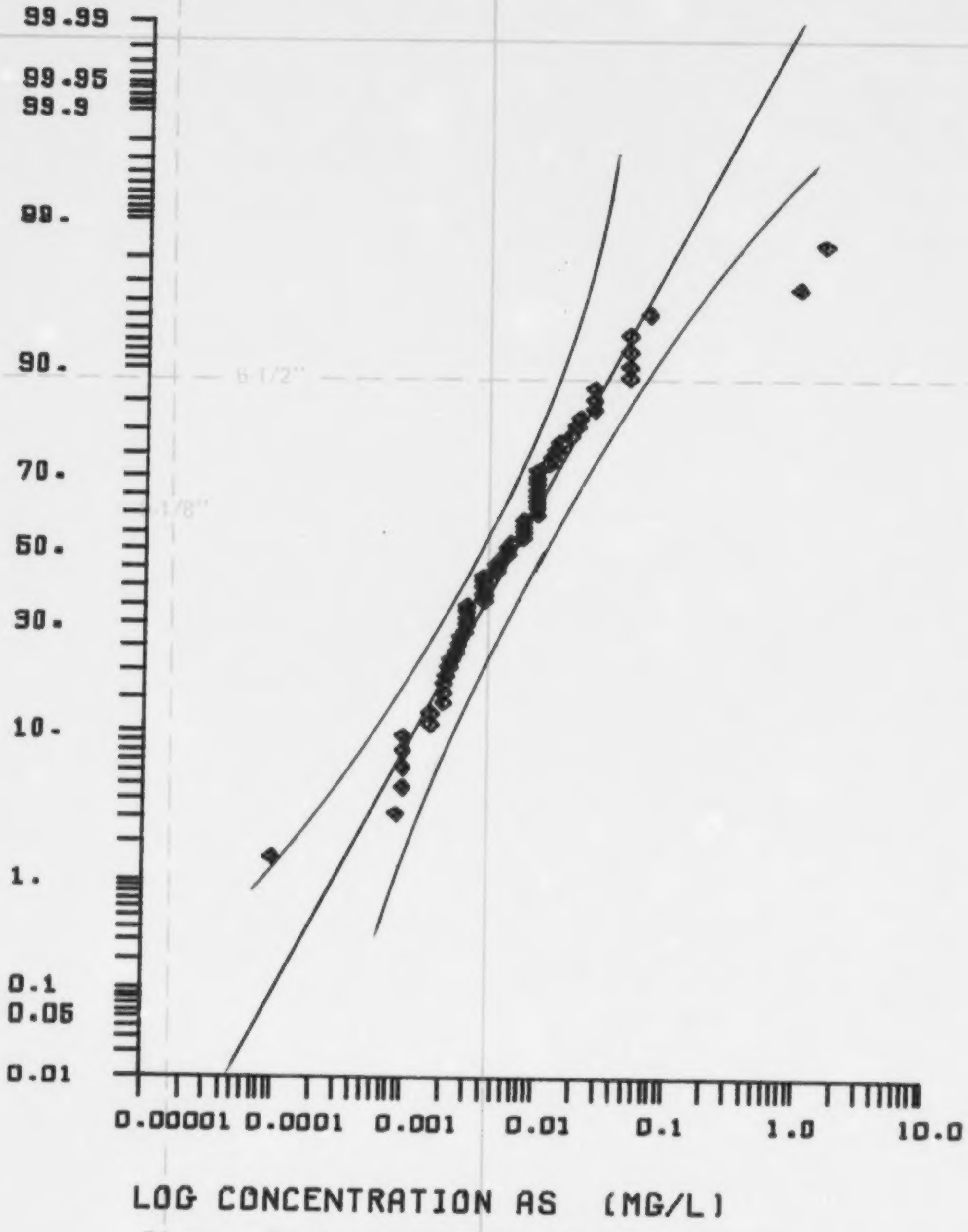

Figure 7. Log probability plot for reported median Arsenic concentrations.

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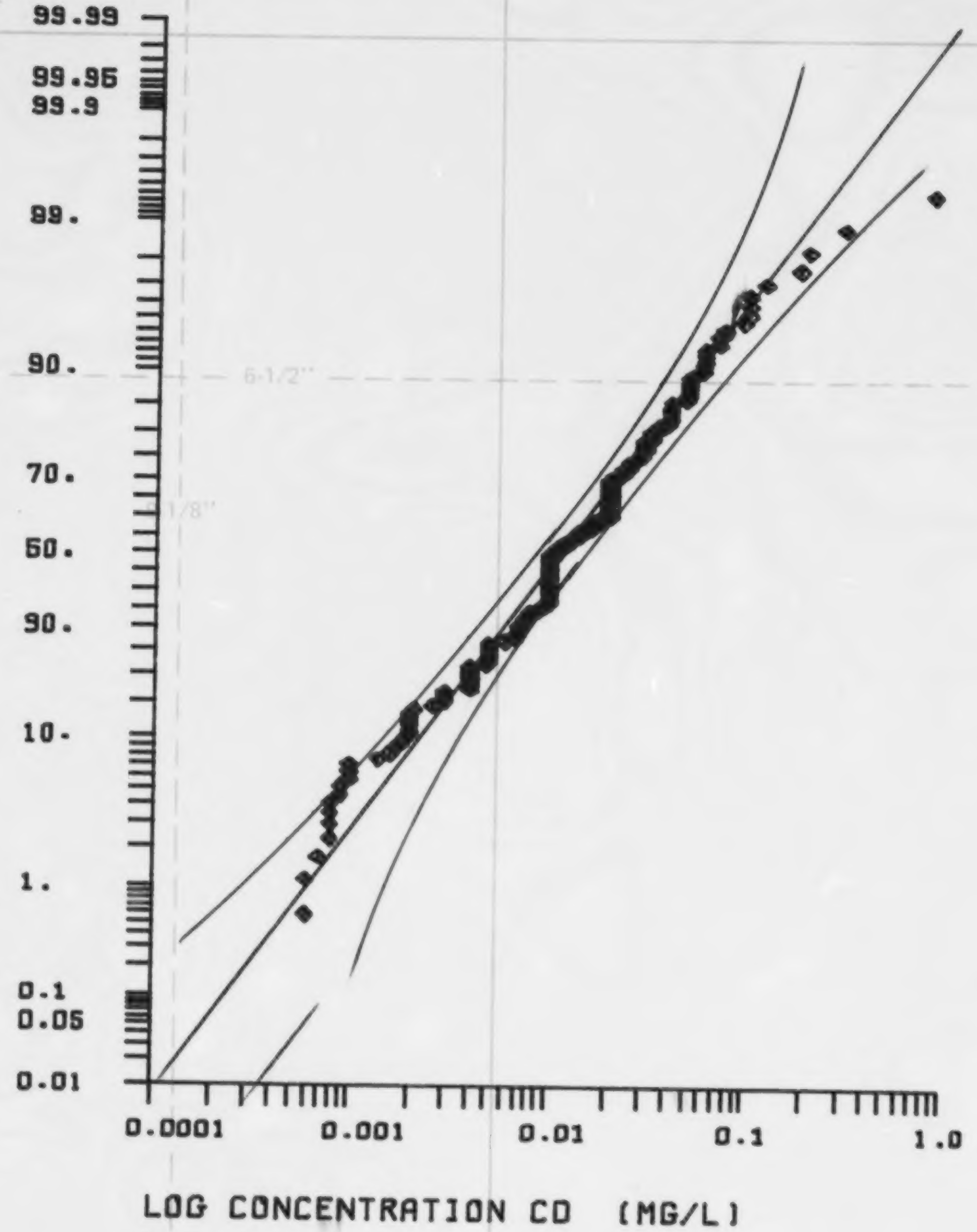

Figure 8. Log probability plot for reported median Cadmium concentrations.

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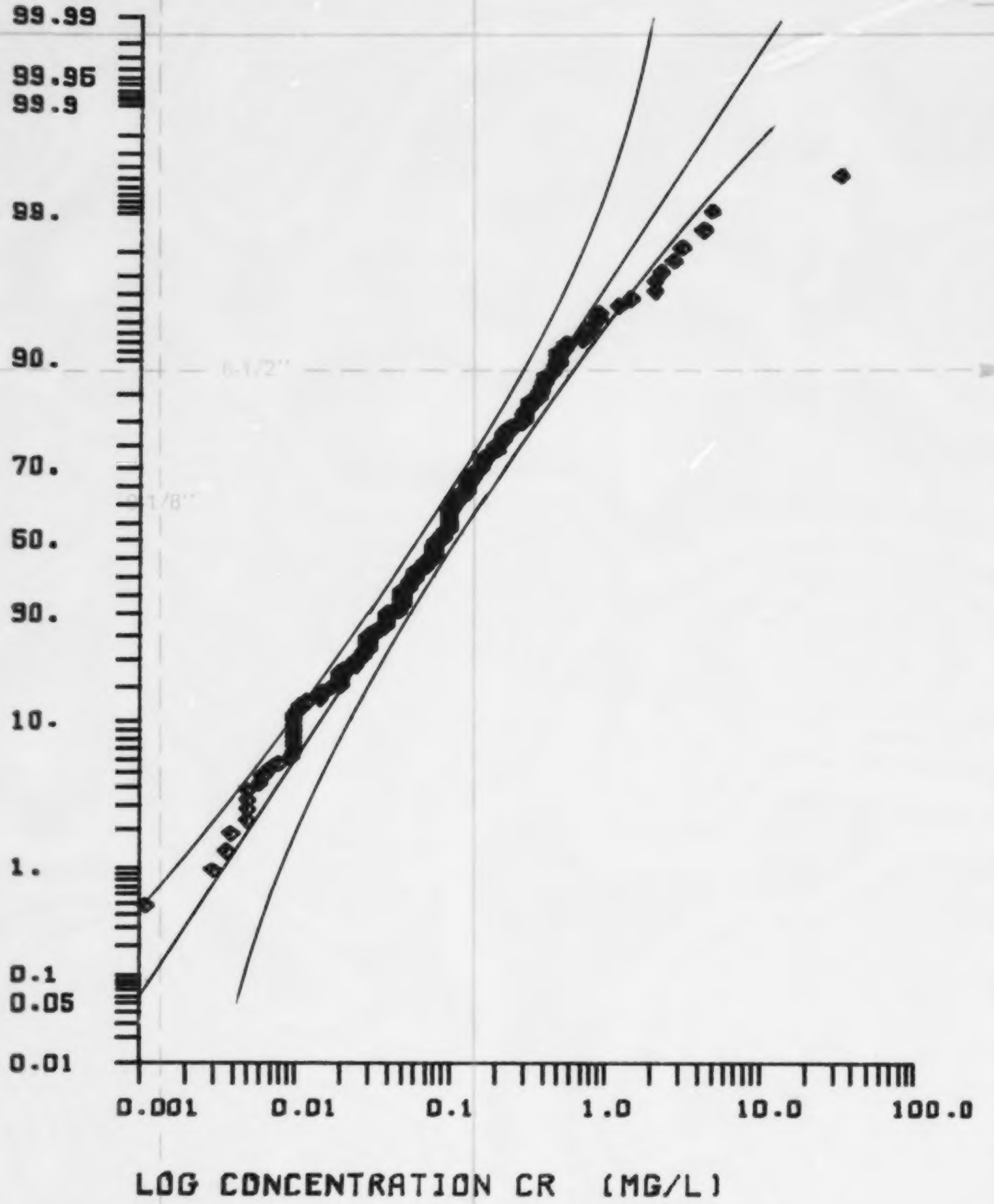

Figure 9. Log probability plot for reported median Chromium concentrations.

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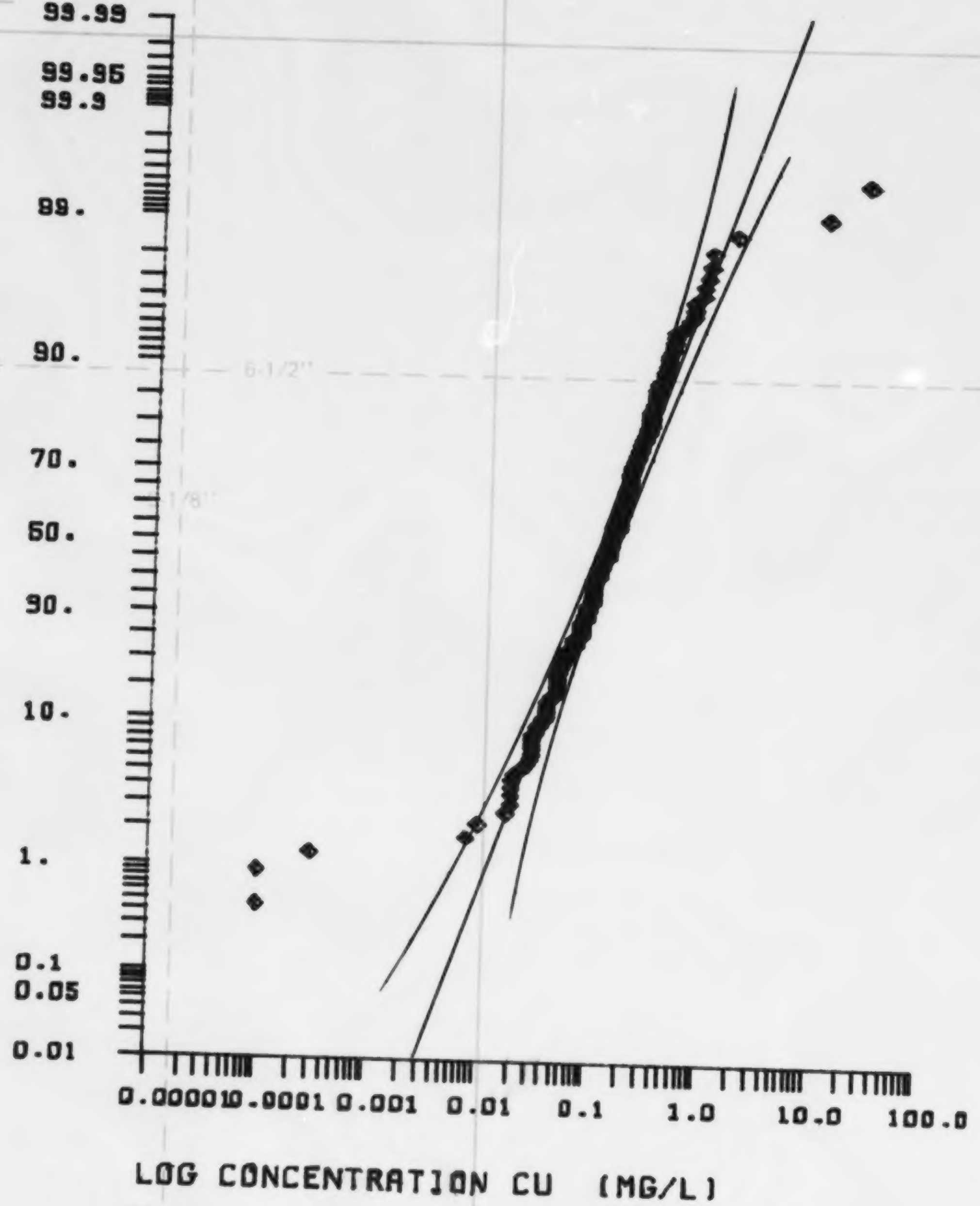

Figure 10. Log probability plot for reported median Copper concentrations.

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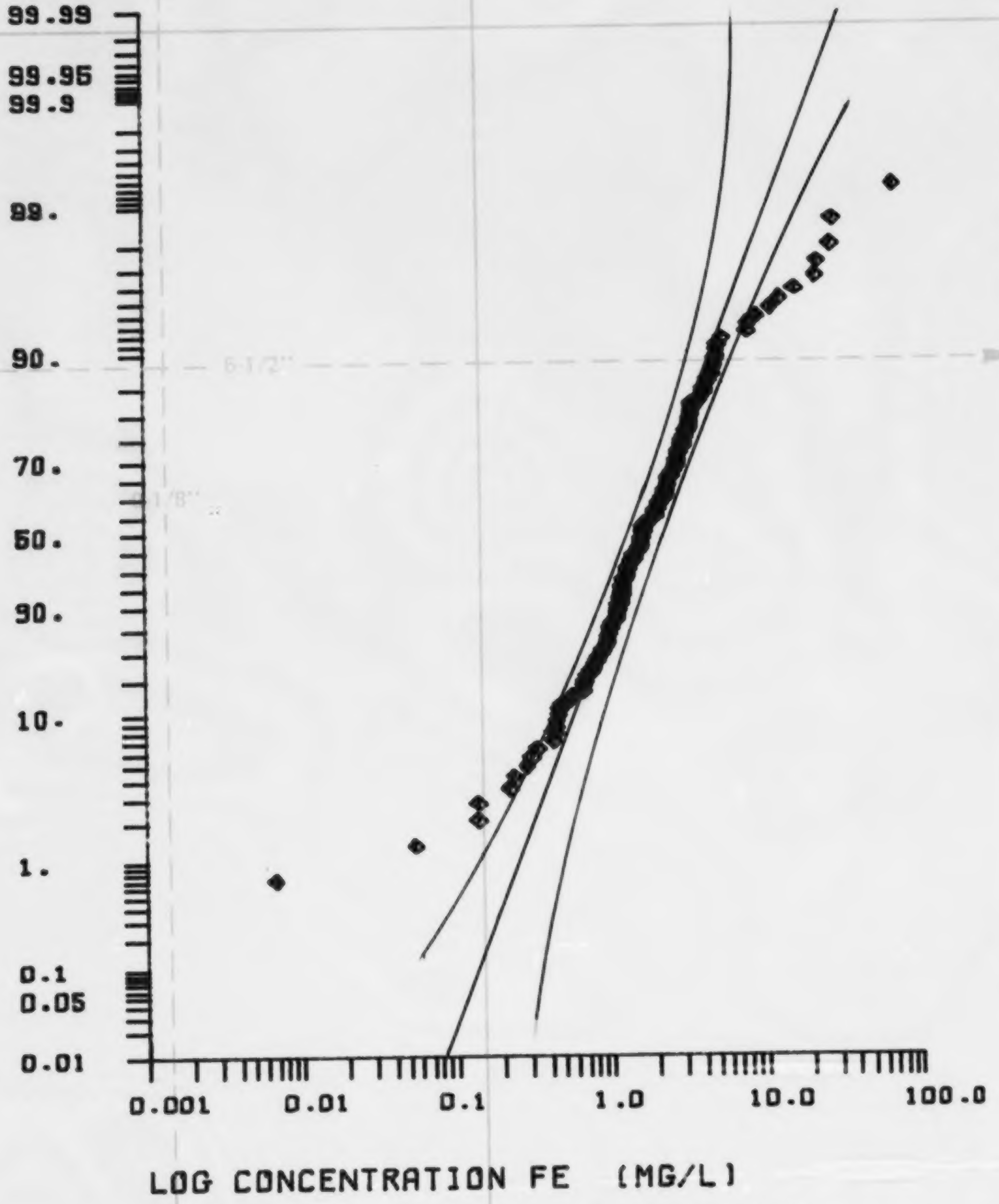

Figure 11. Log probability plot for reported median Iron concentrations.

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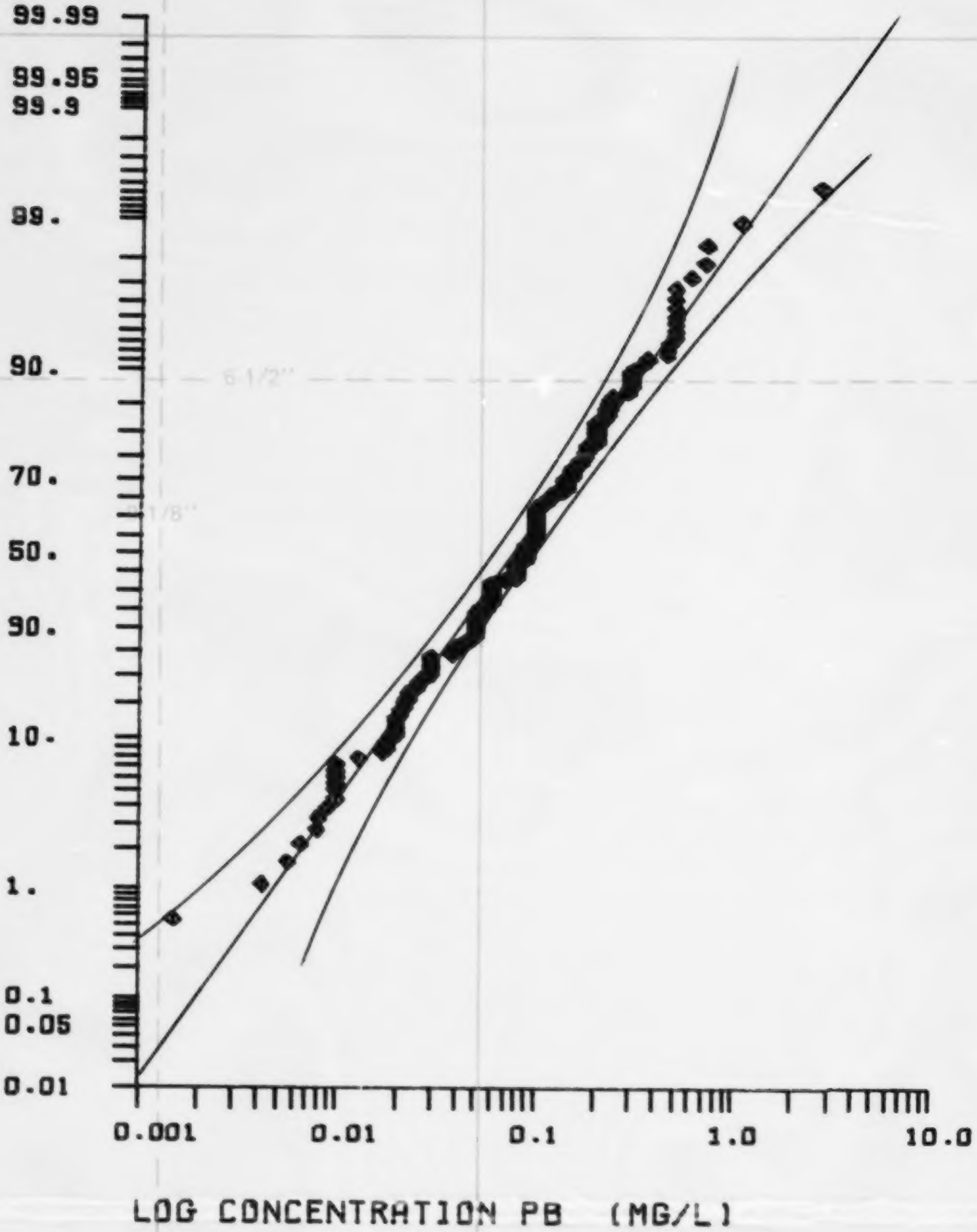

Figure 12. Log probability plot for reported median Lead concentrations.

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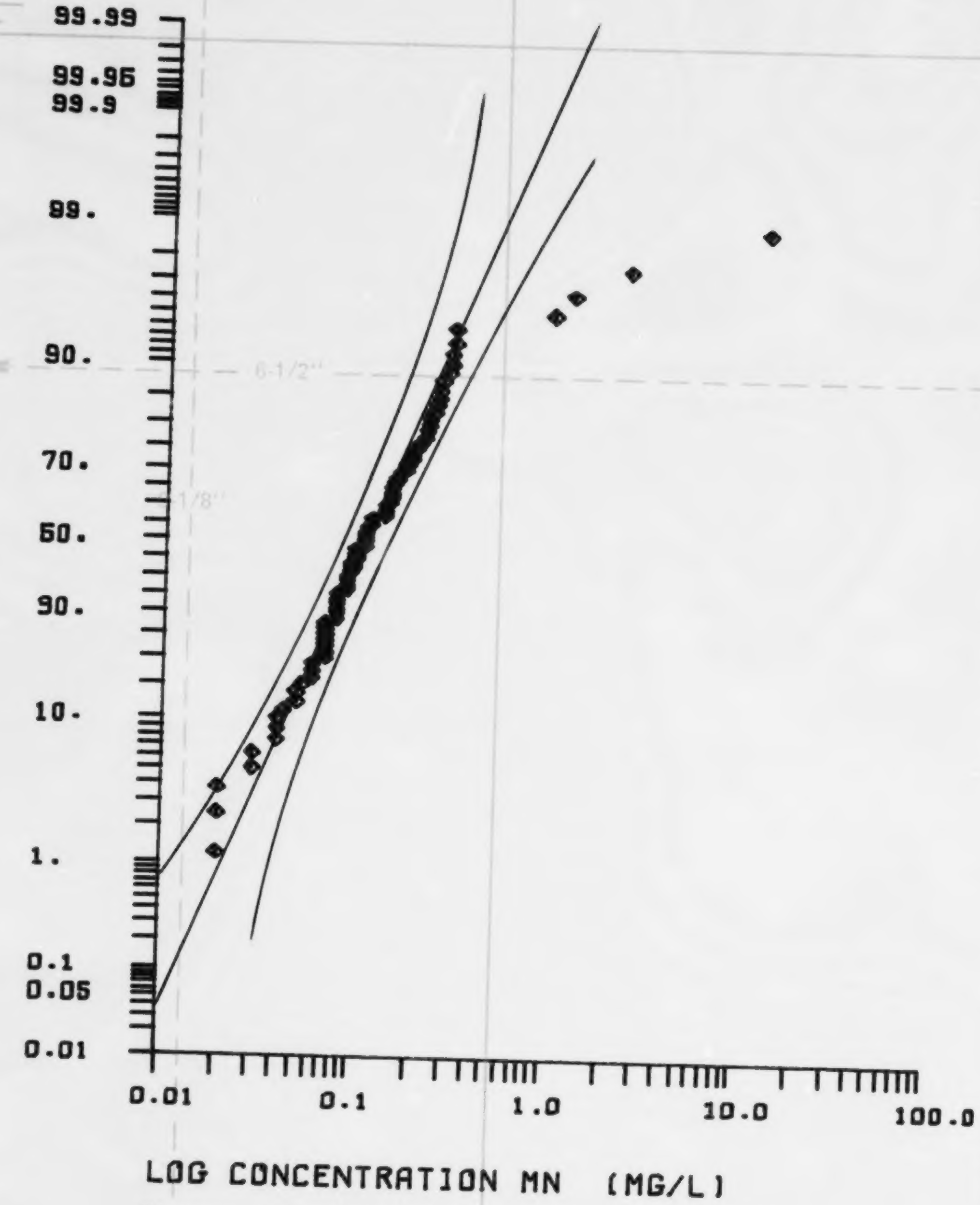

Figure 13. Log probability plot for reported median Manganese concentrations.

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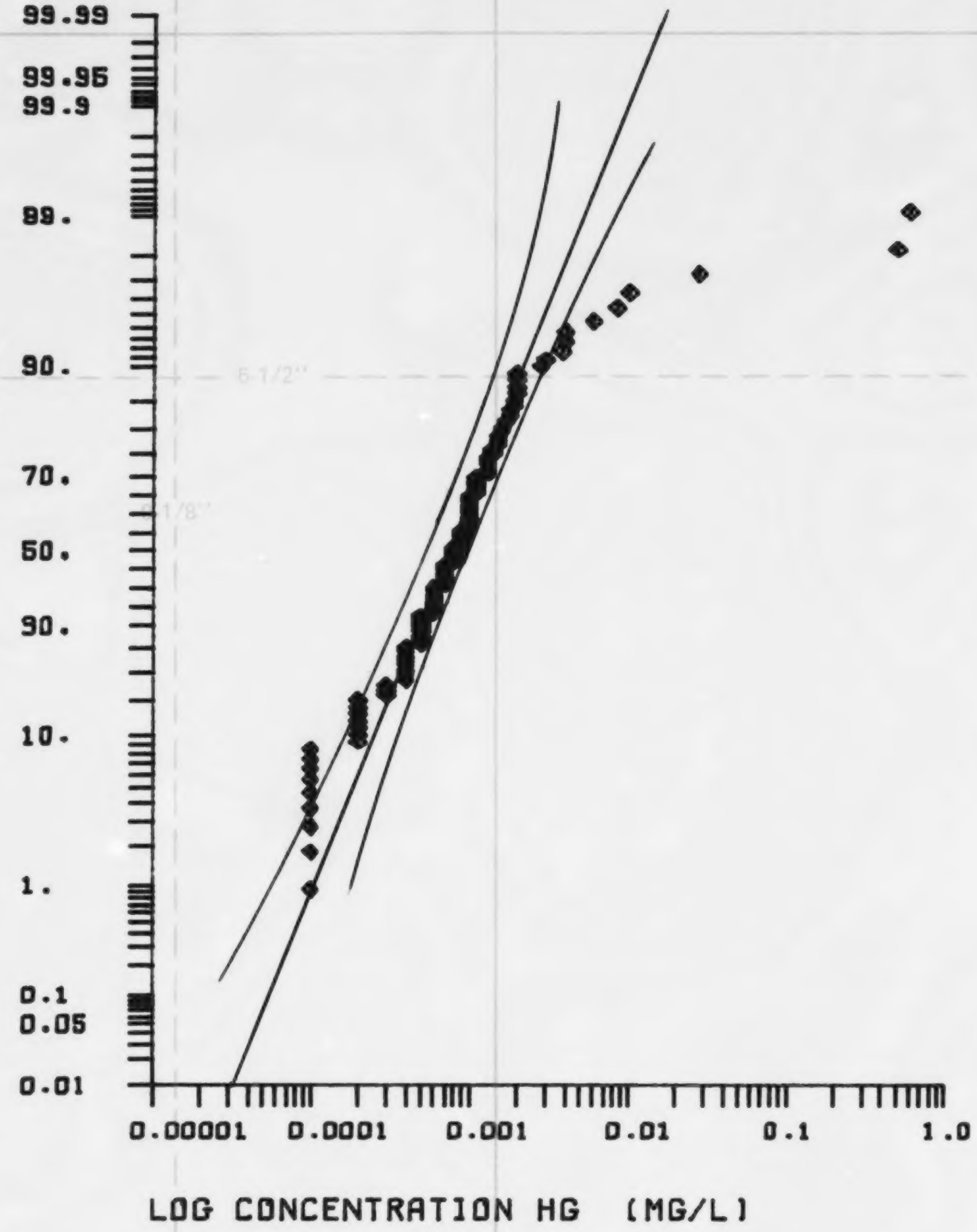

Figure 14. Log probability plot for reported median Mercury concentrations.

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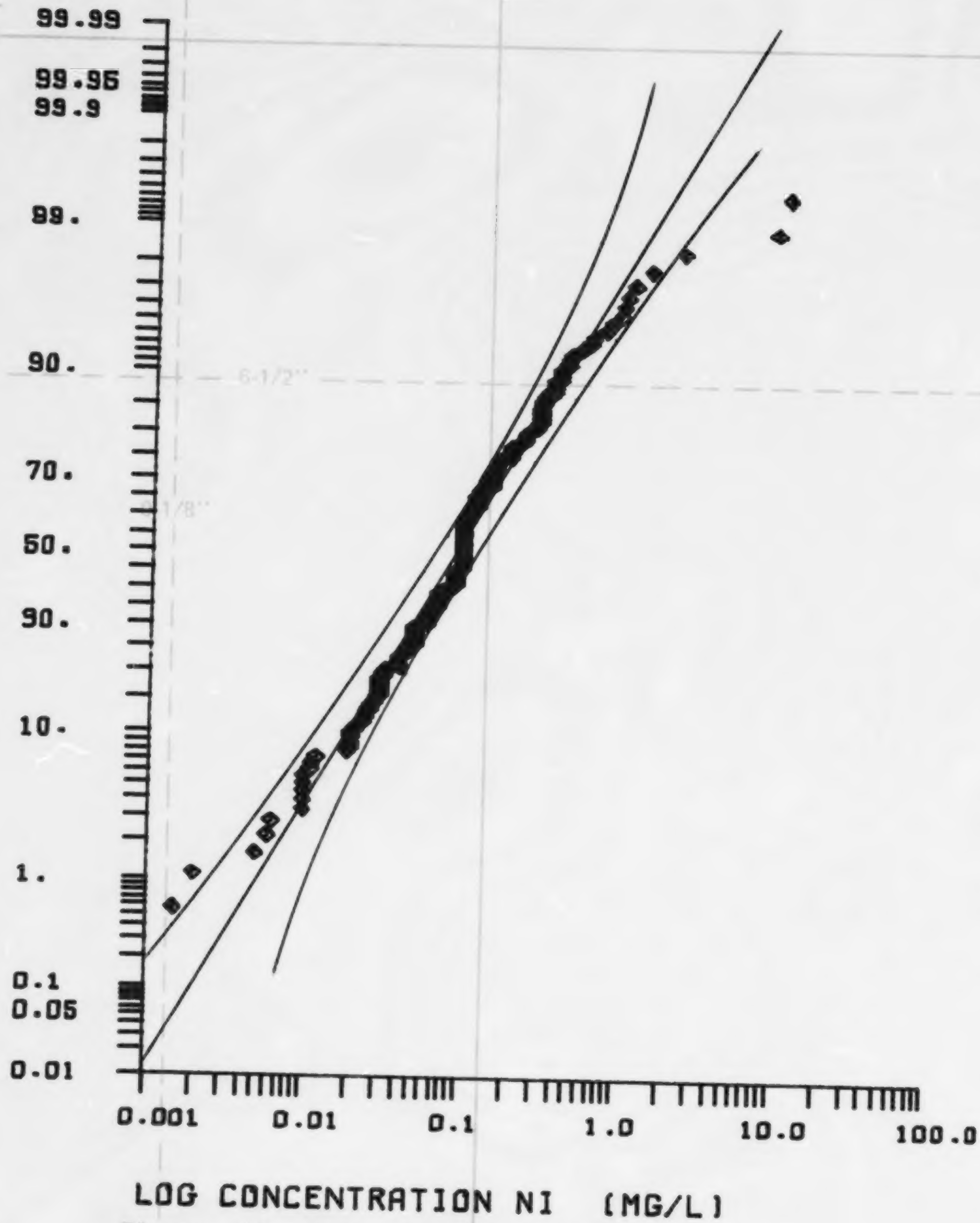

Figure 15. Log probability plot for reported median Nickel concentrations.

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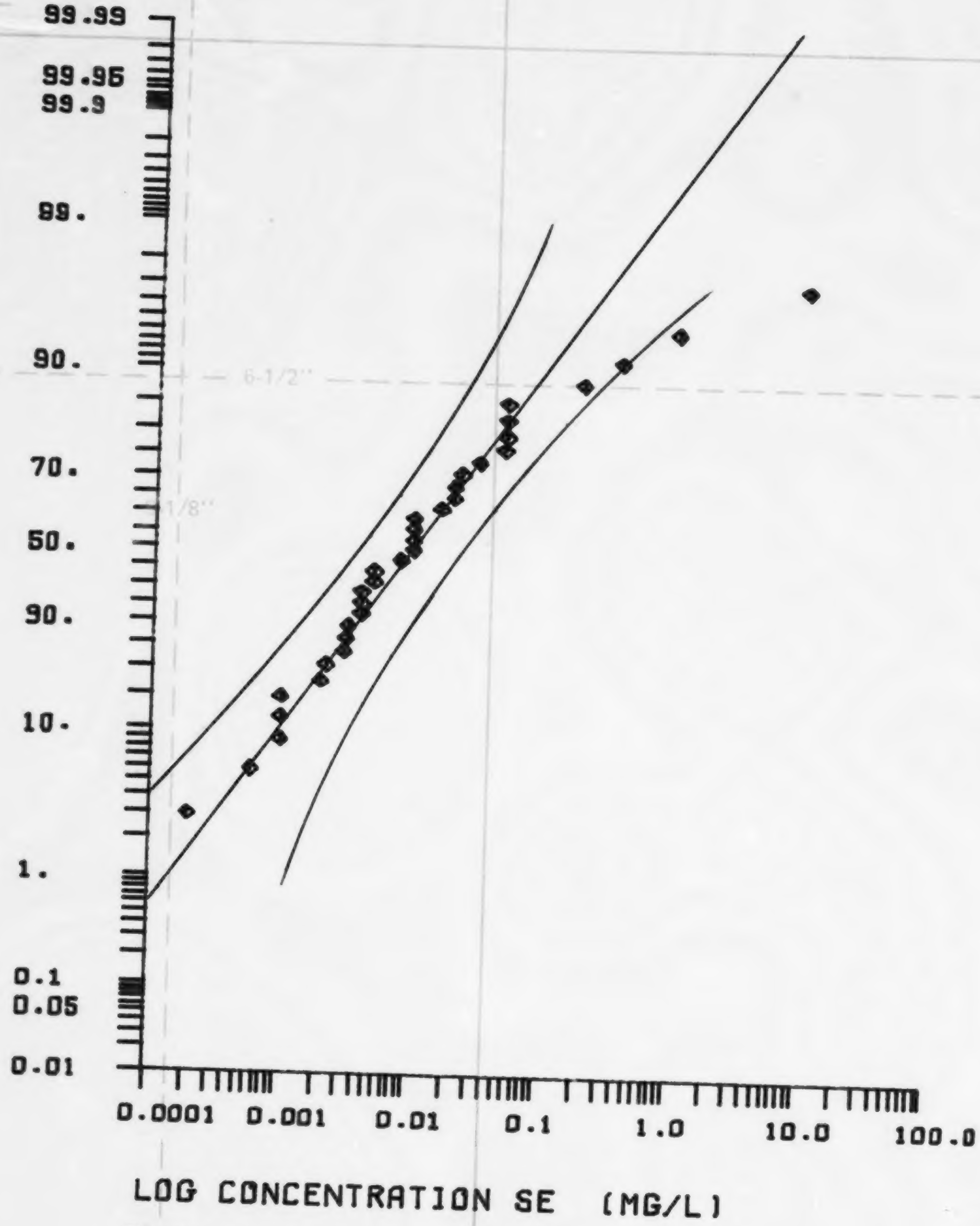

Figure 16. Log probability plot for reported median Selenium concentrations.

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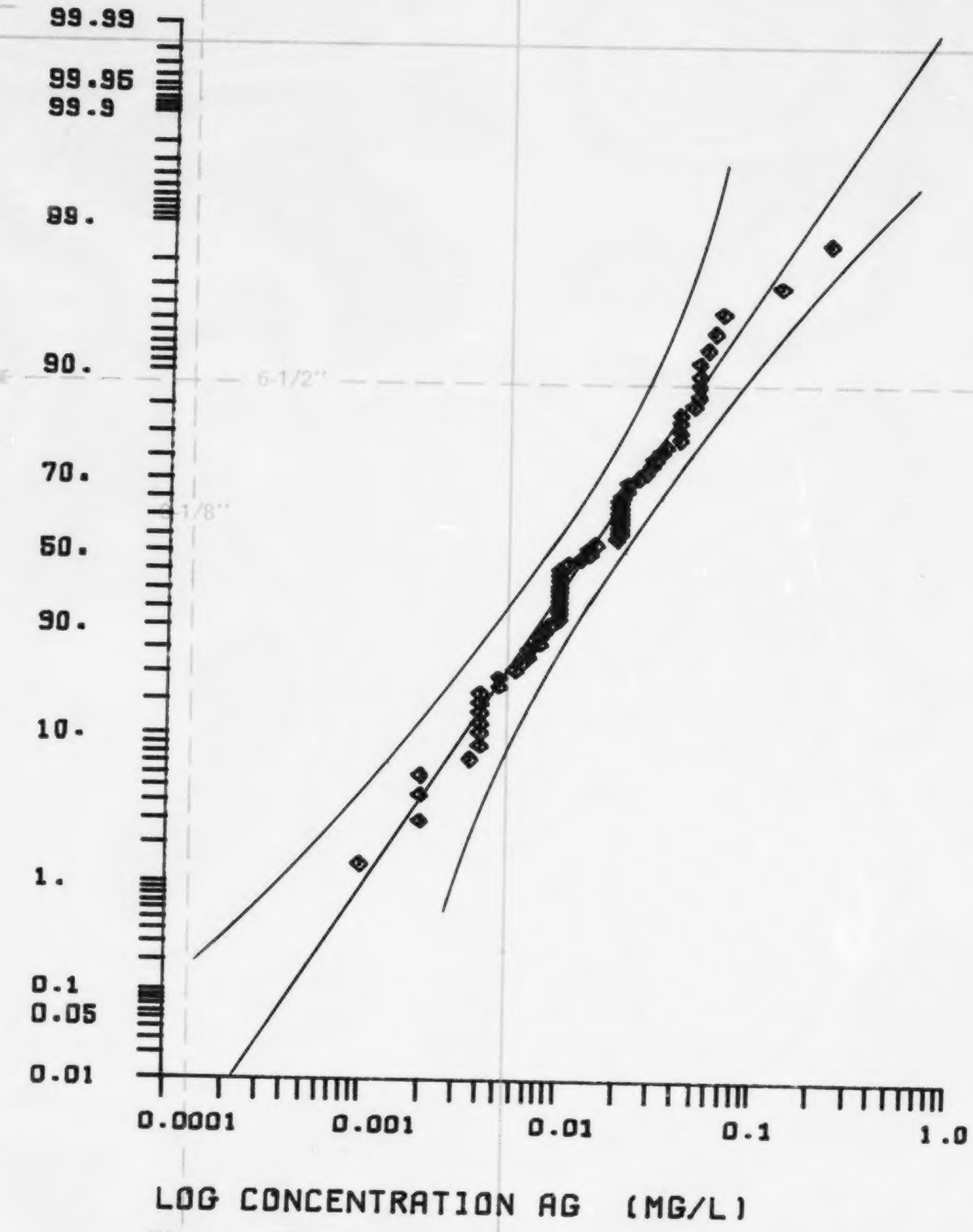

Figure 17. Log probability plot for reported median Silver concentrations.

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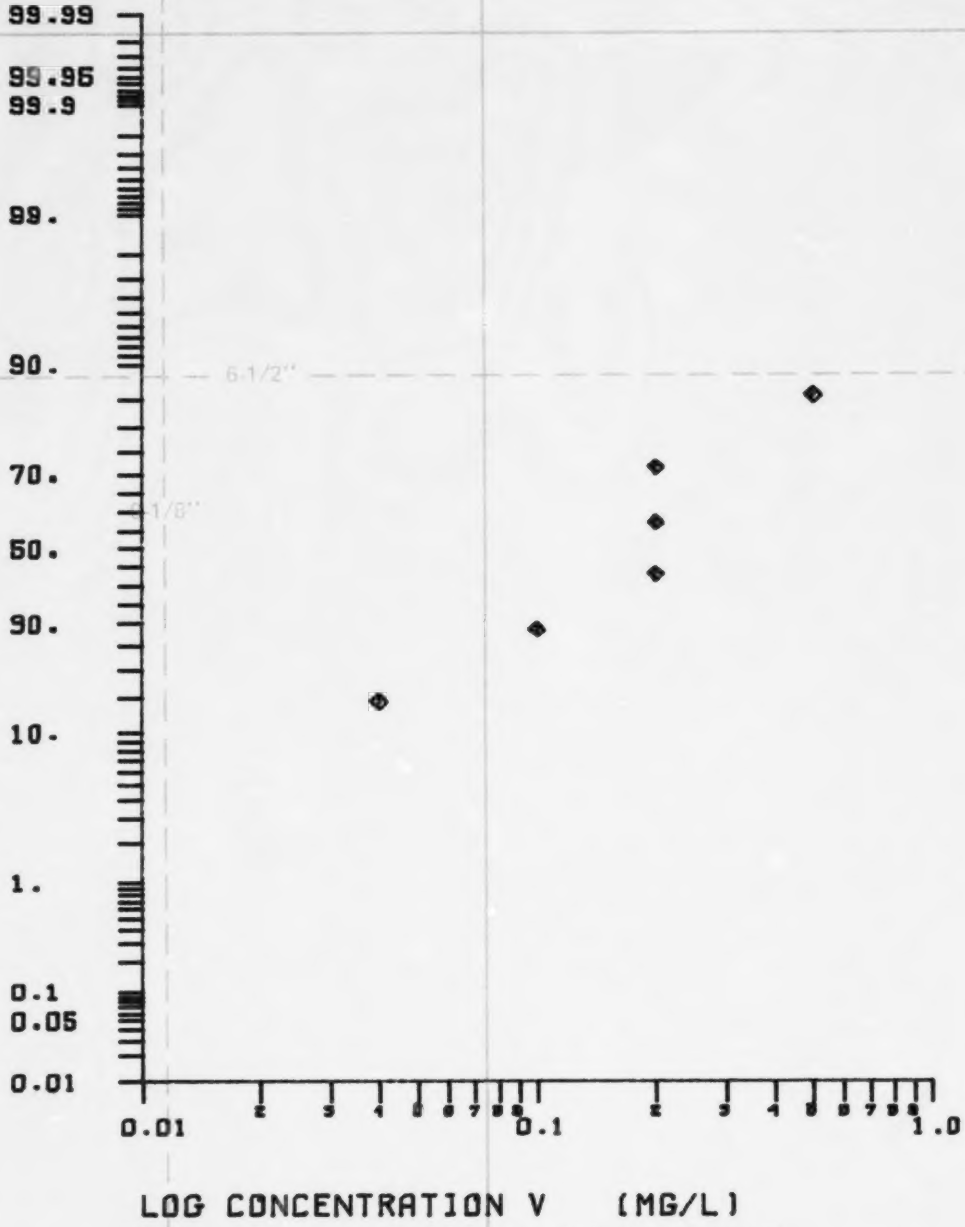

Figure 18. Log probability plot for reported median Vanadium concentrations.

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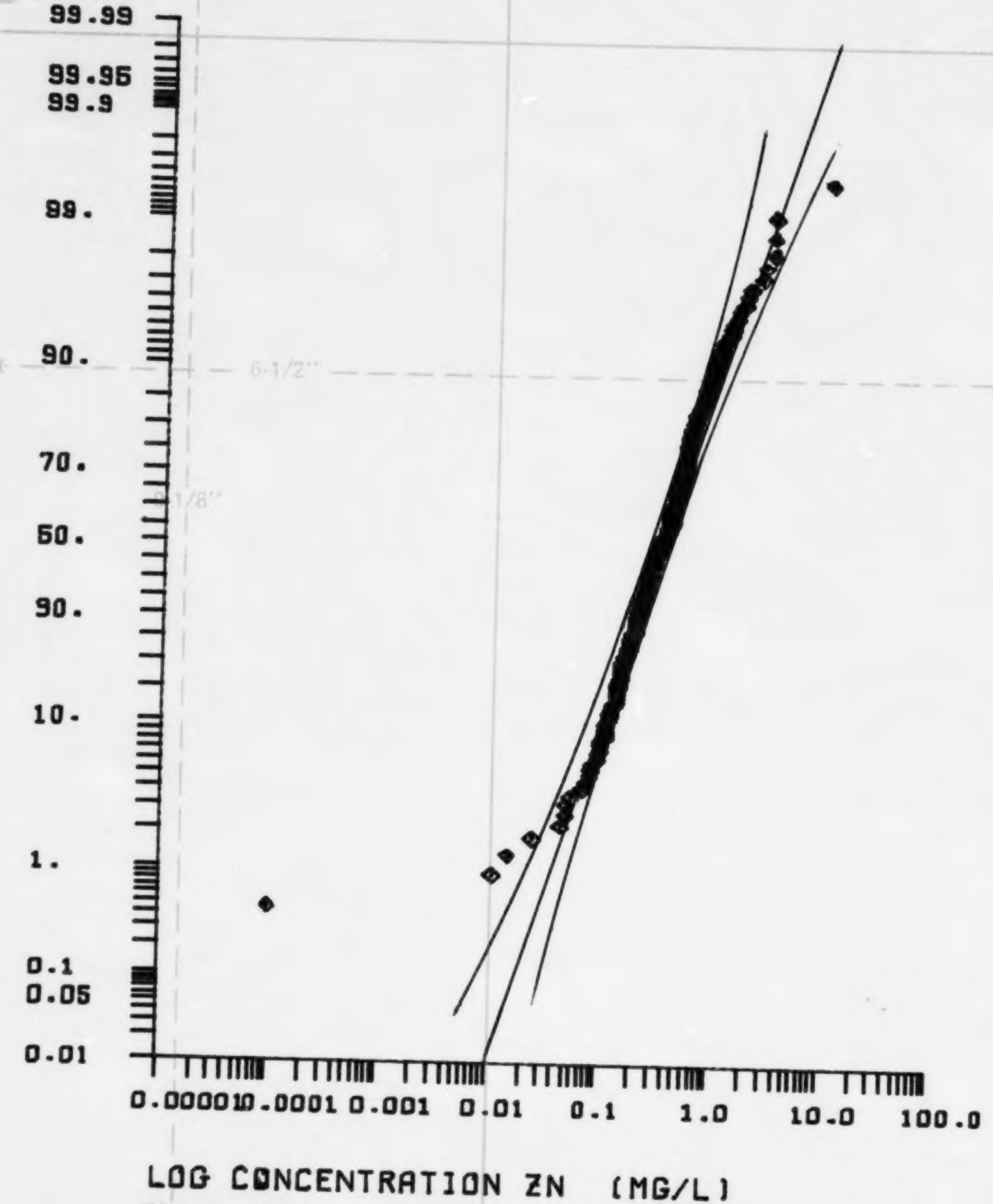

Figure 19. Log probability plot for reported median Zinc concentrations.

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SECTION 6
DATA BASE ANALYSIS

RELATIONSHIP BETWEEN CONCENTRATION AND DESCRIPTORS

The relationship between the various descriptors selected and median concentrations is illustrated for cadmium and zinc median concentrations versus percent of industrial flow in Figures 20 and 21 respectively. Plots for other metals yielded similar scattergrams. Furthermore, examination for both parametric (Pearson) and nonparametric (Spearman and Kendall) associations did not yield large r values for any of the descriptors, including percent industrial flow. While these results may be contrary to expectations and results from specific studies on a smaller population size, they are not suprising when the entire data base is used and emphasize the need to examine with judgement. First, several of the descriptors which would be expected to influence metals concentrations, work in opposition to each other. Secondly, variations in sample types, frequency, analytical method used and quality assurance program (if any) would lead to further noise in the data set. Additional and more sophisticated examination of the data is required.

In essence, many questions concerning heavy metal concentrations in wastewater can and must be asked. First, are the concentrations of heavy metals highly related to the industrial contribution of the total flow? Second, do concentrations show seasonal trends controlled by the amount of infiltration and the existence of combined sewers? Third, do heavy metal concentrations differ significantly for small cities as compared to large ones? Fourth are there large differences among cities in the concentrations of heavy metals? Although each of these questions is important, they do not exhaust all important areas of concern and represent on[illegible]mples for which the data gathered as a part of this research project might be used.

Before any of these questions might be answered, it is important to present a complete characterization of the data. This will be done in two parts: (1) each data category collected will be reviewed and (2) a summation and evaluation of the complete data set will be given. Besides metals concentration data, each city was asked to provide several types of information for each facility where wastewater treatment plant influent samples were collected and measured. This information included the type of analytical measurement method, type of sample and the process of sample handling, the average daily flow of the treatment plant, the percentage of the total flow attributed to industry, the percentage of the total BOD loading attributed to industry, relative amount of infiltration, and the amount of the sewage collection system that is a combined stormwater-sewage collection system. Each of these types of information can be classified as to the degree of confidence that one can place with the information. For those types of information dealing with sampling technique and measurement method, one can be quite confident that what information is provided is accurate in

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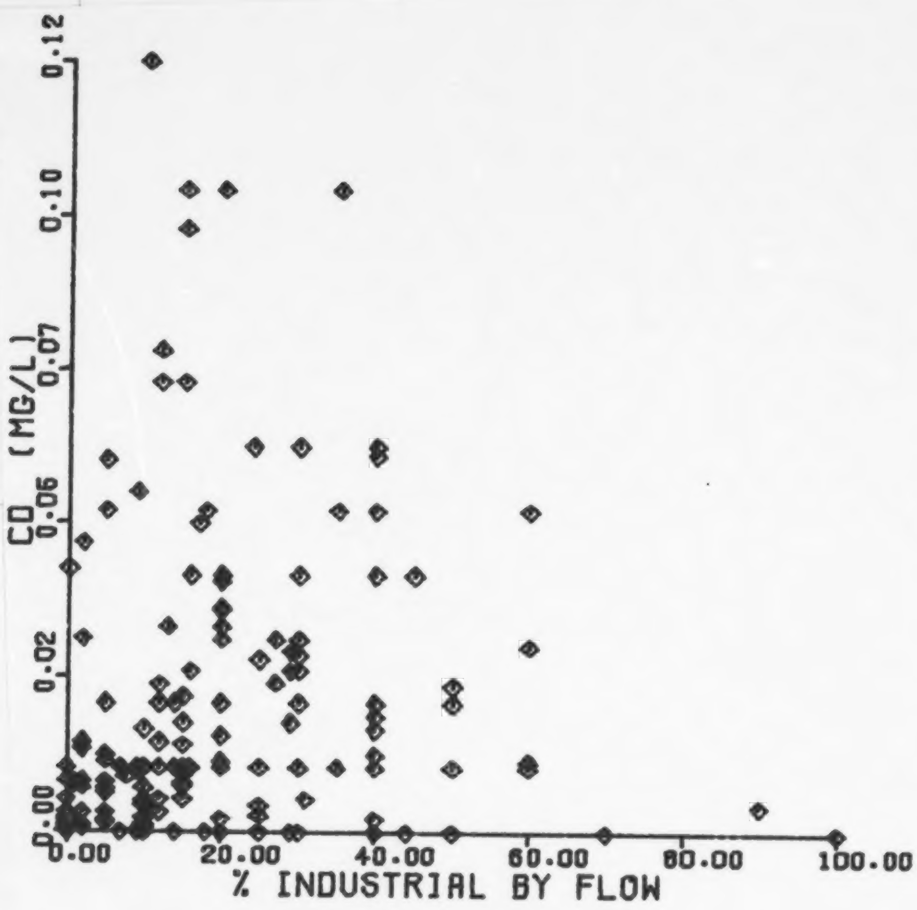

Figure 20. Distribution of individual plant median Cadmium concentrations as a function of industrial contribution to total plant flow.

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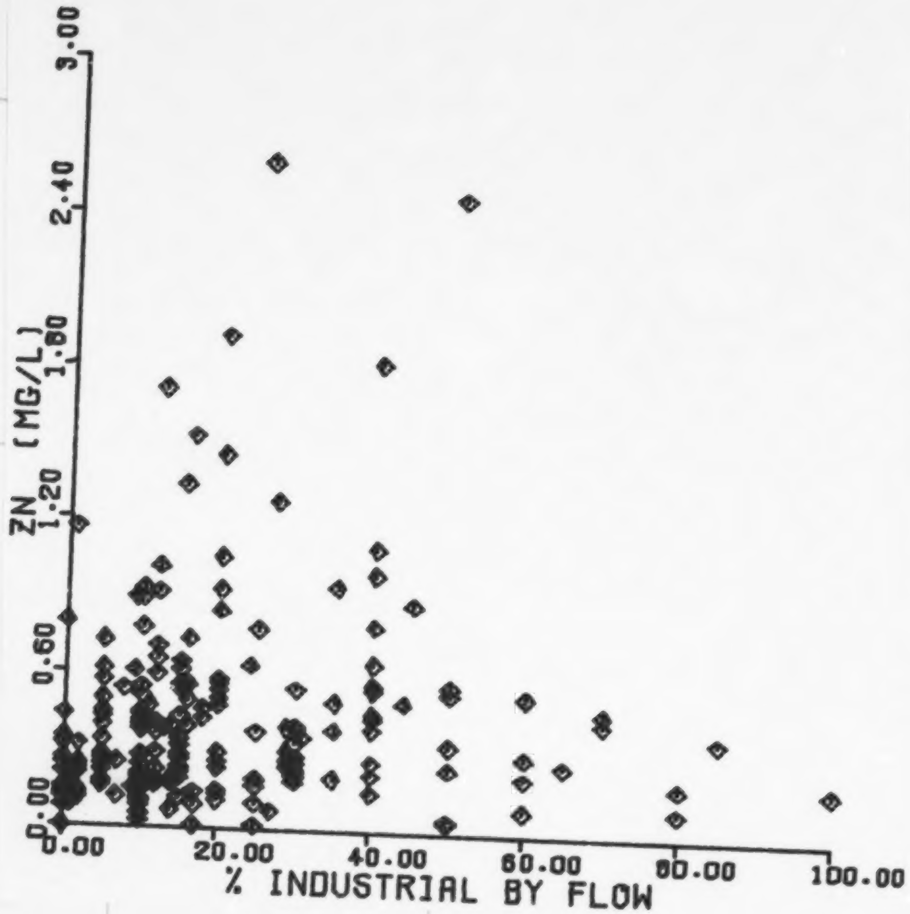

Figure 21. Distribution of individual plant median zinc concentrations as a function of industrial contribution to total plant flow.

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description. However, other responses like the percentage of industrial flow may either represent an accurate measurement or in many cases a guess. Each data category is listed in Table 19 along with the classification of either high confidence or variable confidence.

Some of the most important data categories needed for analyzing heavy metal concentration relationships fall in the range of variable confidence. For example, average percentage industrial contribution of BOD may be an estimate by the plant operator or lab technician but may be subject to question. In addition, the average percentage of industrial contribution of BOD may not even be representative due to strong seasonal variations like that found in the canning industry. Table 20 lists possible problems that exist with using the specially collected data in inferring the main contributions to metals concentrations at treatment plants.

DATA CHARACTERIZATION

The data collected by the project staff can be characterized in several ways. First, each of the cities visited has been rated in terms of the laboratory evaluation procedure. The validity of the data represented by cities with lab quality scores that missed several critical criteria is questionable. Second, the smaller the number of observations that a city sent, the lower the likelihood that the data were representative of overall concentration characteristics of influent metals for that city. This is especially true if a city is represented by 20 measurements spanning 5 years for a specific metal. In order to examine the data set for each metal, a characterization plot was developed. Figure 22 gives an example of a data characterization plot for zinc. For each city measuring zinc, a point was placed on the figure according to the number of observations made by the city, the lab quality score, and the number of critical questions missed in the laboratory evaluation. The x-axis represents the number of observations in tens and the y-axis represents the following three classes of lab quality scores.

1) Top Section - Lab Quality Score for those that missed no more than one critical question.

2) Middle Section - Lab Quality score for those that missed more than one critical question.

3) Bottom Section - Score Unknown.

To prevent overlapping the symbols on the graph for those with unknown scores, the computer program automatically raised the next print symbol to create a bar for the bottom section. To understand this type of figure more closely, there is one city that had 560 measurements and a score of approximately 95 and missed no more than one critical question. Appendix C gives the data characterization figures for the remaining trace metals plus several other elements that are included in the data set for concentrations of influent wastewater to public operated treatment works.

In order to insure that any analysis is using valid measurements, we could consider using only those cities that did not miss more than one

TABLE 19. DEGREE OF CONFIDENCE IN INFORMATION

Information Category	High	Variable Confidence	Examples
Sampling technique	X		Grab, daily composite, weekly composite, monthly composite, composite proportional to flow, composite proportional to time
Sample preparation	X		Acid hydrolyzed - total or soluble
Analytical Measurement Method	X		AA, HACH, Wet Chemistry
Percent of total flow attributed to industry		X	reported as a range, reported as a guess, estimated through industrial water use, based on metered industrial flow
Percent of BOD Load attributed to industry		X	calculated from metered industrial flow, industrial BOD, total BOD, reported as a guess, reported as a range
Percent of combined sewers		X	reported as a guess, based on miles and size of pipes
Relative amount of infiltration		X	reported in 3 broad classes >100%, 10-100%, <10%

TABLE 20. POSSIBLE DIFFICULTIES ENCOUNTERED WITH RELATING METAL CONCENTRATIONS USING AVERAGE WASTEWATER TREATMENT PLANT VALUES.

Data Category	Potential Difficulty
Percent Combined Sewers	This value becomes important only when rainfall is encountered several days before or on the day the sample is taken. Otherwise the metal concentration is not likely to be reflective of the amount of combined sewers. Another complication is that the character of the storm event can also play a strong role in any influence that a combined sewer would exert on metals concentration.
Relative Amount of Infiltration	It is widely accepted that infiltration rates are seasonal in character. For example, when the top layer of soil is frozen in winter months, infiltration is usually considerably lower than right after the spring thaw and during wet spring weather. This means that infiltration becomes important at certain times but not at others. Relating metals concentrations to an average infiltration rate for all times of the year is suspect to errors for most cities.
Percent of Total Flow Attributed to Industry	Besides being possibly seasonal, this average value may not be very reflective of metals concentrations since different types of industries have greater effect on metals than total industry. In addition, pretreatment standards in some cities may mean that an industry suspect of higher effluent metals concentrations may not be high at all. Industries also tend to be metals specific; that is they may be high in one metal but low in others. This means that there will be problems in relating a specific metal concentration to a total industrial average contribution of flow.
Percent of BOD Load Attributed to Industry	Besides being seasonal for many food processing companies, this value may not be reflective of the total BOD generated due to pretreatment processes. Where BOD load is high it is possible that metals concentration is low, but not necessarily since many industries combined make up the total industrial flow.

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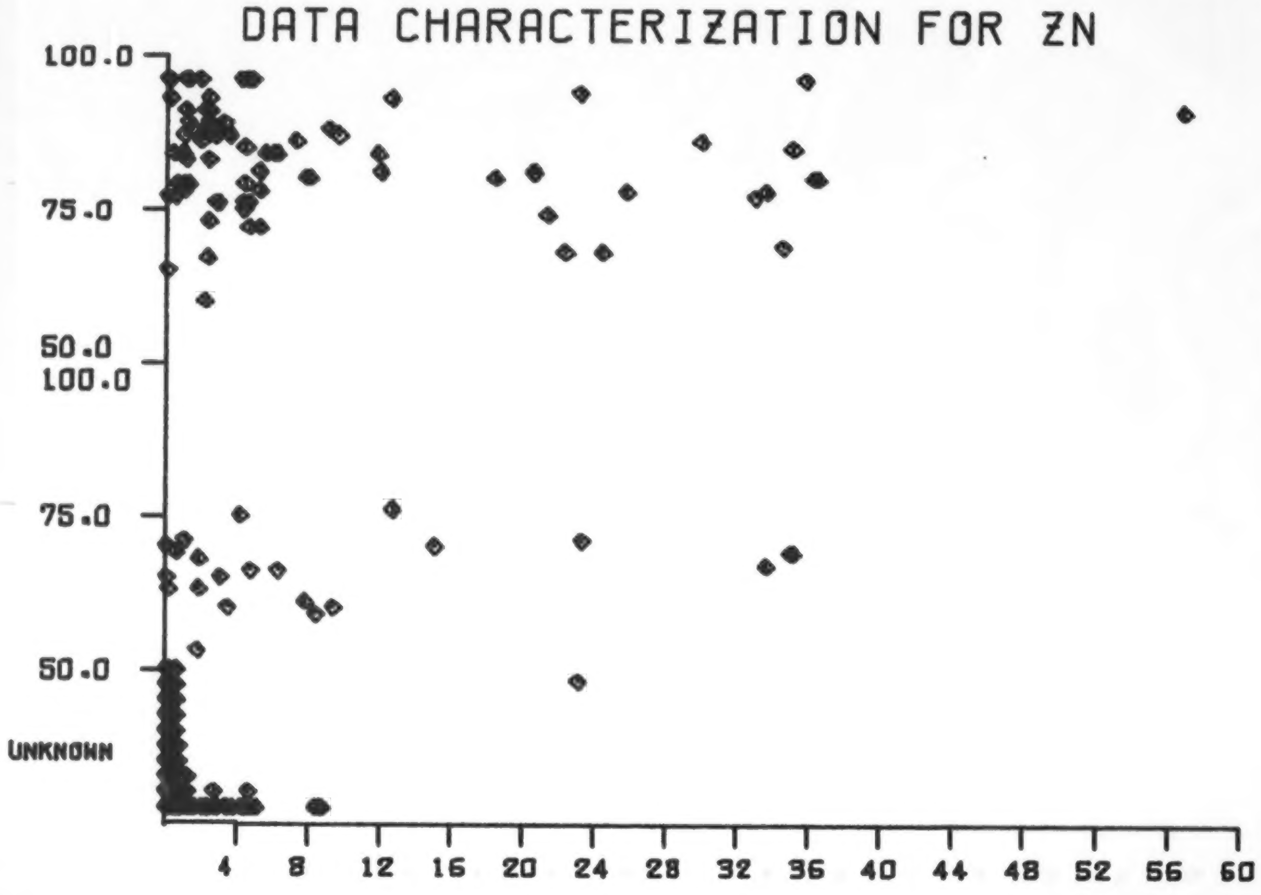

Figure 22. Data Characterization plot for zinc.

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critical question on the Lab Scoring method. Further, in order to have a representative sample for each such city, we should require at least enough measurements to represent the overall characteristics of the city. Suppose we set such a limit at 24 observations for any given element, then many elements in the large data set are adequately represented by only a few cities. For example Al, Sb, As, Ba, Be, B, Co, Cu, Mg, Hg, Mo, K, Se, Ag, Tl, Sn, Si, Ti, V are represented by such few cities, that any statistical inference would be somewhat suspect if generalized beyond the specific data set. Only Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn are represented by a large enough number of cities meeting these two criteria, such that possible statistical inferences can be made. This means that many tests and analyses beyond those for Cu, Cr, Cu, Fe, Pb, Mn, Ni, and Zn would be based on either a rather small set or one for which the validity of the measurements may be questioned.

Since seasonal tests were planned for the data set, data characterization plots were also developed for two different time periods: (1) March and April, and (2) September and October. Typically, March and April tend to be wetter months and September and October tend to be drier months in most places in the U.S., so for our analyses of effect of season given in another section we will define the wet season as March-April and the dry season as September-October. Data characterization plots for the data set for the two seasons are given in Appendix D. By examining these figures, one can conclude that enough data exist for seasonality tests on Cd, Cr, Cu, Fe, Ni and Zn. Problems exist in interpreting results based on analyses of data given for other metals, due to either questionable data or an insufficient number of observations per city.

Profile Evaluation

In order to check for trends in metal concentrations for various cities, two procedures were used: (1) statistical and (2) profile plots. Since the data set represents a large number of cities, each with specific circumstances, it was decided that any visually detectable trends may be identified by developing profile plots. For each city, a profile of median concentrations was plotted on a series of vertical axes like that given in Figure 23. Each axis represents a different metal. If a city measured that metal a point would be placed on that axis associated with how the median concentration for the city relates to the median concentration for all cities. If a city has more than one treatment plant, then profiles are plotted for each treatment plant for which data were provided. The profile line connects adjacent points for the city; when a metal is not measured it is not plotted and a gap appears in the profile. This is to prevent inferring that a metal was measured when a profile line crosses an axis unless that metal was actually measured. Appendix E gives profile plots for the entire data base for Al, Cr, Co, Cu, Fe, Pb, Mn, Hg, Ni, and Zn. City names are not given with the plots. The only feature that is identified is whether or not a city had more than one treatment plant. Plots are numbered across the top edge. Plots numbered 1 through 36 (in Appendix E) represent multiple plant cities where each plot contains only information about that city. Plots numbered 37 through 47 (all in Appendix E) contain single plant city information where approximately eight profiles are given per plot.

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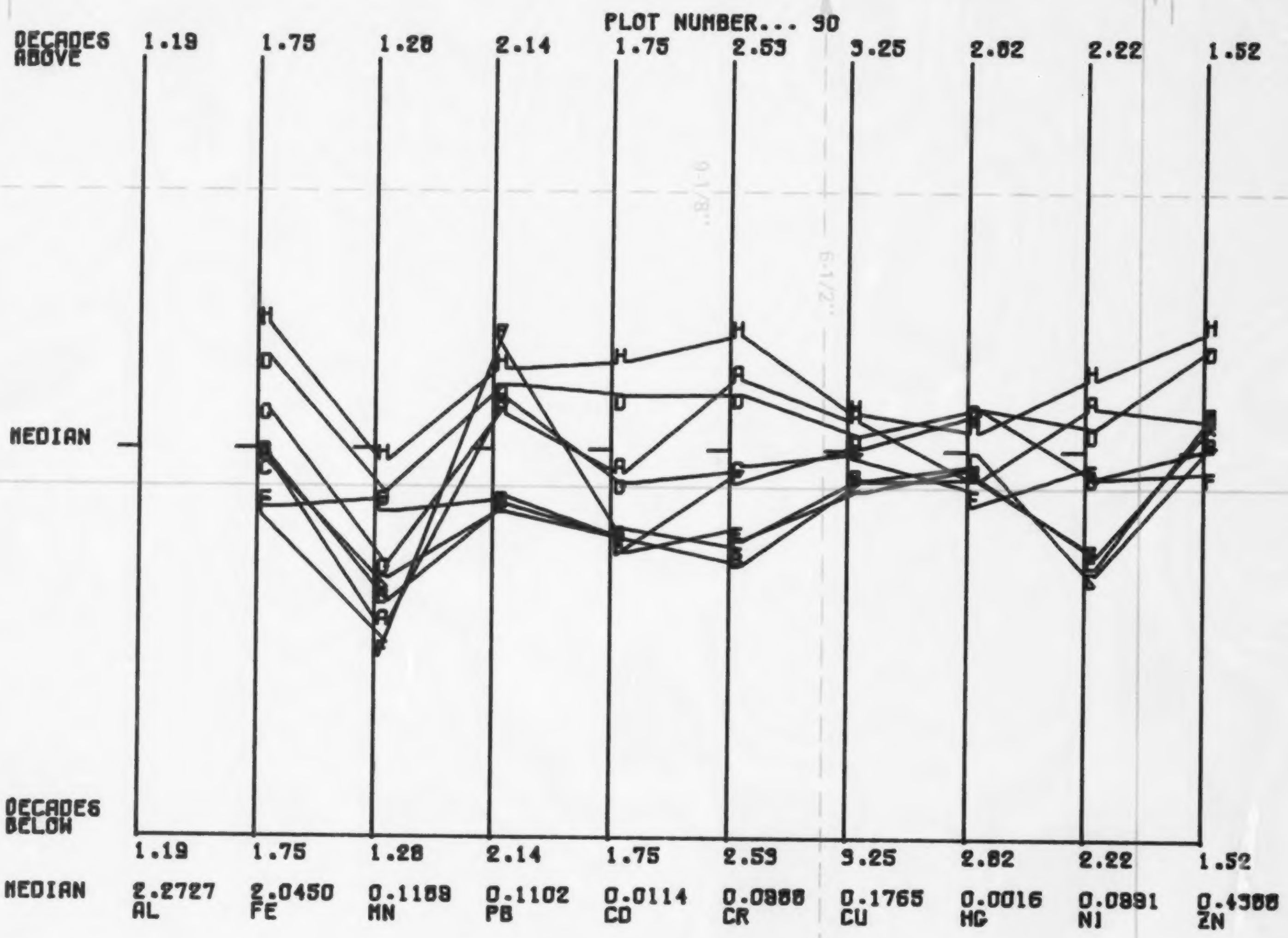

Figure 23. Example city profile plot (8 plants, A-H).

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The plot in Figure 23 (Plot number 30 of the Appendix E Sequence) represents a city with eight treatment plants. The positions for each scale represent the order of magnitude in powers of ten deviation from the overall mean. For example profile H represents a plant with a median concentration of Mn the same as the median Mn concentration for all cities. Plant F for Mn has a median concentration of approximately $10^{-.69}$ less than the overall Mn concentration for all cities. Notice that profile H is higher in Cd, Cr, Cu, Fe, Mn, Ni and Zn than all other plants in the city. However, plant H has a considerably lower percent industry than the other seven plants in the city.

Plot number 2 (Appendix E) represents a two plant city where all reported characteristics are the same except for total flow where one plant is approximately 10 MGD and the other is 20 MGD. Even though everything is reported the same, differences do exist; however, a trend does appear.

Plot number 3 (Appendix E) shows a basic trend as well for the city, however a large range in concentrations for the various plants for a given metal exist. This would suggest that specific circumstances may play a large role in metals concentrations rather than general descriptions like percent industry, combined sewers, and percent infiltration. Although Figure 23 gives an example where the plant with the lowest industrial base has the highest concentrations, examples do appear in the opposite. Plot 6 (Appendix E) represents profiles for a four plant city where the plant represented by profile A has 15% industrial contribution, the plant represented by profile B has 20% industrial contribution, and plants C and D are represented by profiles and industrial contributions of 35% and 0% respectively. Note that profile D is lower in all categories except Hg.

The profile plots are useful in evaluation trends, however, within-city variations appear to be strong and in many cases counter intuitive. If anything, an examination of these plots along with the various city descriptions tend to draw a complicated picture that gives support to the statistical conclusions drawn in a later section; that is, the current descriptions are too general to draw any quantitative functional trends using regression analysis on the data set.

Statistical Evaluation

Seasonal Variations in Heavy Metals Concentration--

For most of the heavy metals the hypothesis that their concentration would be lower in the spring than the fall, due to typically greater rainfall in the spring, was shown to be true for the data analyzed. The differences in the mean concentrations range from 5 to 20% greater in the fall than the spring.

The months March and April were chosen to represent the spring season and the months September and October were chosen to represent the fall season. The number of plants which had enough measurements during these months for statistical analysis is small, therefore the analysis for seasonal differences was carried out on the entire data set rather than a plant by plant basis. The results are therefore weighted in favor of the plants with the greatest number of measurements during these months.

The statistical test chosen for this comparison was the 'T' test. To determine the type of distribution to be used, first the skewness was calculated for the heavy metal concentration and the log of the heavy metal concentration distributions. The results of these calculations are in Table 21. From these results a log-normal distribution was assumed valid for use in the 'T' test. The results of the 'T' test evaluation are shown in Table 22 for both normal and log-normal cases. Significant difference is based on the 95% confidence interval.

Silver, copper, aluminum and cadmium demonstrated a significantly higher concentration in the fall. Chromium, iron, selenium, mercury, lead, and zinc all had apparent higher concentrations in the fall but these were not statistically significant. Manganese and arsenic demonstrated a significantly higher concentration in the spring than the fall.

To understand the possible effects of season on heavy metal concentration it is important to know the variables involved. The variables thought to be important are:

1) Seasonal changes in some industries such as agriculture,

2) The geographic area.
   i) Is rainfall typically higher in the spring or fall?
   ii) What metals are found naturally in the ground near the sewer collection system?
   iii) What metals are found in the water supply before domestic or industrial use?

3) Chemistry of the heavy metal
   i) in industrial processing
   ii) in the soil surrounding the sewers.

4) The presence or absence of combined sewers.

5) The amounts of inflow and infiltration.

6) Since the comparison uses data from only 4 months, the amount of data used was reduced significantly.

Industries associated with agriculture such as canning are busier in the fall than the spring. Since canning uses considerable volumes of process water and likely contributes small quantities of heavy metals, one may see a dilution effect and, thus the concentration of heavy metals is less in the fall in areas where significant amounts of canning are done.

The effect of dilution will have its greatest effect in areas with high amounts of infiltration and/or combined sewers. If the collection system is sanitary only and for the most part water tight, the effect of rainfall will be insignificant. Therefore, the age of the system and the existence of combined sewers will significantly affect the outcome of the comparison between spring and fall months.

TABLE 21. SKEWNESS VALUES FOR DETERMINATION OF TYPE OF DISTRIBUTION FOR MARCH, APRIL, SEPTEMBER & OCTOBER

Metal	Sewer Type	Skewness of Values	Skewness of Log of Values
Ag	Sanitary	7.003	-0.281
	Combined	4.762	1.058
Cu	Sanitary	24.583	0.021
	Combined	5.212	1.191
Mn	Sanitary	12.537	1.125
	Combined	6.789	0.610
Ni	Sanitary	5.791	0.127
	Combined	8.989	-0.111
Cd	Sanitary	4.088	0.023
	Combined	12.425	0.131
Cr	Sanitary	2.633	-0.199
	Combined	10.589	0.004
Fe	Sanitary	6.648	-0.891
	Combined	20.560	0.115
As	Sanitary	10.653	0.506
	Combined	2.055	0.600
Hg	Sanitary	8.541	0.307
	Combined	14.136	0.256
Pb	Sanitary	5.779	-0.499
	Combined	6.312	-0.615
Zn	Sanitary	3.678	-0.645
	Combined	6.026	-1.165

TABLE 22. APPLICATION OF THE 'T' TEST EVALUATION OF SIGNIFICANT DIFFERENCES IN METALS CONCENTRATION BETWEEN SPRING AND FALL

Metal	Type Comparison	Conc. from Sept & Oct	Conc. from Mar & Apr	F	Significant Difference
Ag	Normal	0.0360	0.0165	0.0001	Yes
	Log	0.0179	0.0122	0.0001	Yes
Cu	Normal	0.4190	0.5276	0.0001	Yes
	Log	0.1563	0.1479	0.0006	Yes
Mn	Normal	0.2027	0.1440	0.0001	Yes
	Log	0.0970	0.1173	0.0001	Yes
Al	Normal	3.0107	2.3900	0.0410	Yes
	Log	2.1532	1.2329	0.0001	Yes
Cd	Normal	0.0300	0.0316	0.0001	Yes
	Log	0.0187	0.0143	0.0103	Yes
Ni	Normal	0.2859	0.2610	0.0001	Yes
	Log	0.1375	0.1239	0.9022	No
Cr	Normal	0.5441	0.4624	0.0001	Yes
	Log	0.1489	0.1269	0.1839	No
Fe	Normal	5.8512	3.5158	0.0001	Yes
	Log	2.3623	1.8993	0.4249	No
Se	Normal	0.2859	0.2610	0.0001	Yes
	Log	0.1375	0.1239	0.9022	No
As	Normal	0.0251	0.0475	0.4050	No
	Log	0.0090	0.0098	0.0004	Yes
Hg	Normal	0.1216	0.0920	0.1556	No
	Log	0.0032	0.0026	0.0861	No
Pb	Normal	0.1636	0.1422	0.1300	No
	Log	0.1114	0.0922	0.8290	No
Zn	Normal	0.6473	0.5895	0.0112	No
	Log	0.3733	0.3410	0.7297	No

To test the hypothesis that combined sewers will show a greater difference in seasonal variation than sanitary sewers, a 'T' test was performed comparing the spring and fall months for cities with combined sewers along with a 'T' test comparing the spring and fall months for cities with sanitary sewers. The results of these comparisons are in Table 23. Again the number of plants which had enough measurements during these months is small and by dividing this small number into two more categories one obtains a small enough number of points so that this analysis should be viewed with some skepticism.

The one metal showing different results than for the previous 'T' test on seasonality was iron. It appears that iron has a larger concentration in combined sewer systems. This may be because combined sewer systems are typically found in older systems and iron piping was used more in the past.

Copper, chromium, arsenic, and mercury were interesting results in that they showed significant differences for combined sewers only. This would tend to support the theory that seasonal metal variation is due to seasonal variation in rainfall.

In conclusion it may be stated that in general the concentrations of heavy metals tend to be higher in the fall than the spring. Upon examining the concentrations from cities having combined sewers it appears that the difference between heavy metal concentrations in the fall and spring are even more significant. Since the number of data points used for these analyses are small and the quality of the data is unknown, the results concluded here should be viewed only as possible trends.

Variations in Heavy Metals Concentrations Due to Industrial Flow--

Analysis of the heavy metals data demonstrates that industry is a major contributor of heavy metals to Public Operated Treatment Works, however no general correlation between heavy metals concentrations in the influent waste stream and the percent industrial flow of the waste stream could be found. A general correlation between the heavy metals concentrations in the influent waste stream may be developed if more detailed information were available for each city.

To demonstrate that industry significantly contributes heavy metals to Public Operated Treatment Works, heavy metal concentrations from treatment plants reporting 5-100% industrial flow were compared to heavy metal concentrations for treatment plants reporting 0-4% industrial flow.

The type of distribution needs to be known before some significance tests can be used to compare means of the low industry and high industry city groups. To determine the type of distribution first the skewness was calculated for the entire data set on the heavy metal concentrations and on the log of the heavy metal concentrations. The results of these calculations are contained in Table 24. From these results log normality figures 6 through 19 in section 5 were drawn. Each point in these log-probability plots represents the median metal concentration for a particular plant. The plots for aluminum, mercury and iron have more than 5% of the points falling outside of the 99% confidence bounds, however the points which fall outside

TABLE 23. 'T' TEST FOR SEASONAL DIFFERENCES ANALYSIS (BASED ON LOG VALUES) FOR SANITARY AND COMBINED SEWERS

Metal	Sewer Type	Conc. From Sept & Oct	Conc. From Mar & Apr	F	Significant Difference
Ag	Sanitary	0.295	0.0172	0.0001	Yes
	Combined	0.210	0.0135	0.0007	Yes
Cu	Sanitary	0.1495	0.1202	0.1868	No
	Combined	0.1763	0.2008	0.0203	Yes
Mn	Sanitary	0.0916	0.070	0.0001	Yes
	Combined	0.1046	0.1264	0.0098	Yes
Ni	Sanitary	0.1326	0.1218	0.9030	No
	Combined	0.1224	0.1163	0.6786	No
Cd	Sanitary	0.0231	0.0182	0.0025	Yes
	Combined	0.0159	0.0107	0.5053	No
Cr	Sanitary	0.1254	0.0985	0.2873	No
	Combined	0.1986	0.1662	0.0028	Yes
Fe	Sanitary	1.4934	1.295	0.0014	Yes
	Combined	3.8646	2.6867	0.0045	Yes
As	Sanitary	0.0092	0.0058	0.1043	No
	Combined	0.0140	0.0268	0.0009	Yes
Hg	Sanitary	0.0014	0.0006	0.2380	No
	Combined	0.0012	0.0015	0.0001	Yes
Pb	Sanitary	0.0909	0.0739	0.2308	No
	Combined	0.1528	0.1097	0.3207	No
Zn	Sanitary	0.3417	0.3300	0.6369	No
	Combined	0.4314	0.3409	0.3158	No

TABLE 24. SKEWNESS FOR THE COMPILED VERSION OF THE DATA SET

Metal	Type Comparison	Skewness for Concentration of Metals		Percent of 0.0 Values Lost	
		< 4% Industry	> 4% Industry	< 4% Industry	> 4% Industry
As	Normal	1.62	4.65		
	Log	-0.24	0.35		20%
Cr	Normal	9.35	18.25		
	Log	-0.05	0.15	2%	8%
Cu	Normal	4.16	8.04		
	Log	-0.25	0.54	1%	6%
Fe	Normal	18.11	26.97		
	Log	0.23	-0.52		1%
Se	Normal	1.89	16.63		
	Log	0.09	-0.74		39%
Cd	Normal	6.41	8.49		
	Log	-0.01	-0.12	1%	23%
Ni	Normal	9.70	44.89		
	Log	0.02	0.10	5%	11%
Zn	Normal	5.10	7.70		
	Log	-0.47	-0.52	1%	9%
Ag	Normal	5.44	8.15		
	Log	0.76	0.31		15%
Al	Normal	2.98	16.03		
	Log	-0.02	-1.17		1%
Pb	Normal	16.88	15.38		
	Log	-1.86	-0.32		12%
Hg	Normal	8.96	47.74		
	Log	0.82	0.59	3%	7%
Mn	Normal	13.99	17.58		
	Log	1.47	0.58		1%

occur at the extremes of the plot where it is not as critical, therefore, a log-normal distribution is assumed for the median metal concentrations.

Since the metals data are log normally distributed, the student 'T' test can be used to determine whether a statistical difference exists between the mean of the logs of the (0-4%) industrial group and the mean of the logs of the 5-100% industrial group.

The 'T' test was performed on the log of the values for the entire data set. The results are given in Table 25. Significant difference is based on the 95% confidence interval. Arsenic, chromium, copper, iron, cadmium, nickel, selenium, and zinc have significantly higher concentrations for the treatment plants reporting 5-100% industrial flow than for the treatment plants reporting 0-4 industrial flow. Silver, aluminum, lead and mercury are not significantly different for these two groups. Manganese has a significantly lower concentration from the treatment plants reporting 5-100% industrial flow than treatment plants reporting 0-4% industrial flow.

Many factors associated with industrial contribution of heavy metals to Public Operated Treatment Works are potentially important. The main factors include:

(1) Type and diversity of industry contributing to influent.

(2) Pretreatment processes by industry
    a) Implemented for economic reasons
    b) Required by ordinance

(3) Chemistry of heavy metal under consideration

(4) Characteristics of the collection system
    a) Combined sewers/separate storm collection system
    b) Amount of infiltration
    c) Type of materials used, age of construction, and present condition

(5) Non-industrial sources of the heavy metal under consideration.

The type of industry will have a great influence on heavy metal concentration. A plater will produce more heavy metal waste than an agricultural or food processing industry. Unfortunately, the data set includes only sketchy information on type and diversity of industries for each city. If heavy metal concentrations are largely dependent on industrial sources then it is hypothesized that a correlation between the concentration of heavy metals and the reported percent industrial flow that a public operated treatment plant receives could be developed. Heavy metal concentrations were plotted against the percent industrial flow. These plots are shown in Appendix F in Figures F-1 through F-13. Figures F-14 through F-23 were developed for only those cities with at least 25 observations and with a high LQI score. Due to the fact that the data are log normally distributed, the heavy metal concentrations are plotted on a log scale. From a visual inspection, there appear to be no discernable trends.

TABLE 25. COMPARISON OF INFLUENT CONCENTRATIONS FOR NONINDUSTRIAL CITIES WITH THOSE OF CITIES CONTAINING INDUSTRY.

Metal	Type Comparison	Conc. from < 4% Industry	Conc. from > 4% Industry	F	Significant Difference
As	Normal	0.0036	0.0606	0.0001	Yes
	Log	0.0025	0.1355	0.0001	Yes
Cr	Normal	0.0750	0.4759	0.0001	Yes
	Log	0.0250	0.1451	0.0010	Yes
Cu	Normal	0.1507	0.4891	0.0001	Yes
	Log	0.0948	0.1513	0.0001	Yes
Fe	Normal	2.5808	5.3385	0.0001	Yes
	Log	1.5157	2.1567	0.0001	Yes
Se	Normal	0.0007	0.0754	0.0001	Yes
	Log	0.0006	0.0239	0.0001	Yes
Cd	Normal	0.0320	0.0303	0.0001	Yes
	Log	0.0095	0.0166	0.0077	Yes
Ni	Normal	0.0854	0.3188	0.0001	Yes
	Log	0.0371	0.1400	0.0064	Yes
Zn	Normal	0.4174	0.6396	0.0001	Yes
	Log	0.2384	0.3539	0.0342	Yes
Ag	Normal	0.0050	0.0290	0.0001	Yes
	Log	0.0030	0.0188	0.0884	No
Al	Normal	1.7956	3.4566	0.0001	Yes
	Log	0.8190	1.9559	0.1095	No
Pb	Normal	0.0739	0.1610	0.8175	No
	Log	0.0418	0.1032	0.6633	No
Hg	Normal	0.0023	0.0258	0.0001	Yes
	Log	0.0006	0.0012	0.8778	No
Mn	Normal	0.2289	0.1774	0.0001	Yes
	Log	0.1479	0.1239	0.0004	Yes

Since the specific estimates on percent industrial flow are questionable, the scatter in Figures F-1 through F-23 may be due to basic errors in these estimates. It is possible, however, to analyze industrial contributions without using industrial flow values. This can be done by checking to see if the concentrations of two metals which are generally considered to be a function of industrial activity are indeed related.

The concentration of one heavy metal was plotted against the concentration of another heavy metal. The results of these plots are shown in Appendix G in Figures G-1 through G-8. All of these plots use only data from cities with a high LQI and at least 25 observations. Both log and normal axes were used to examine any possible trends more thoroughly.

There are no discernible correlations for any of the plots, however a few do appear to show a very general trend of metal concentrations increasing simultaneously. It is felt that these trends are not well enough defined to view their cause as entirely industrial in origin.

In spite of the lack of correlation between percent industrial flow and metals concentration, the data base does allow sorting out the background or base level contribution of several metals to POTWs from domestic sources. Upon closer examination and sorting of the data, particularly in conjunction with information on dominant industry types, better association between percent industry and metals concentrations might be expected. Table 26 indicates that a number of plants are available with low industrial contributions.

To do a more accurate interpretation of the heavy metals data more detailed information on the type and diversity of industry that each treatment plant serves should be obtained along with the amount of pretreatment done by each industry. If each industry were given a weight, which would be a function of the degree of pretreatment and expected contribution of a particular heavy metal, then a relationship as follows may be developed:

$$\bar{C}_m = C_m(W_{1m}I_1+W_{2m}I_2+W_{nm}I_n)+(B^*_m\ 1-\sum_{i=1} I_i)$$

Where $\bar{C}$ = concentration of heavy metal m in treatment plant influent
W_i = weight for industry i
I_i = % of flow due to industry i
B = concentration of heavy metal in 0% industrial conditions
C = correlation coefficient

The percentage of heavy metals from industry for a particular plant would then be:

$$\frac{C(\sum_{i=1}^{n} w_i I_i}{C_m}$$

TABLE 26. BREAKDOWN OF PLANTS REPORTING IN THE RANGE OF 0-4% INDUSTRIAL FLOW CONTRIBUTION

Metal	Number of Plants Reporting Indicated Industrial Contributions				
	0%	1%	2%	3%	4%
Cd	20	4	11	0	0
Cr	21	4	13	0	1
Cu	22	4	13	0	1
Hg	12	2	8	0	0
Ni	10	2	12	0	0
Pb	19	3	12	0	0
Zn	22	4	13	0	0

Industry may pretreat their waste for economic reasons. Metals such as silver and mercury are valuable and therefore recovering the metal from the waste stream by the industry may prove to be economical. Other metals which may not be economical to remove for the industry may cause operating and economic problems at the public operated treatment plant. If it presents significant problems at the treatment plant, the city may invoke a pretreatment ordinance either requiring the industry to provide pretreatment or to pay an extra treatment fee. Unfortunately information on pretreatment ordinances is not included in the data base.

Heavy metal concentrations may be a function of nonindustrial sources. For example, if combined sewers are used, then influent concentrations of lead and zinc would be affected by lead from automobile fuel and zinc from automobile tires. Other metals such as manganese occur naturally in some areas. Higher concentrations may be due to higher concentrations in the water supply. In addition, higher levels may result from inflow and infiltration. Copper and iron piping used in houses, industry, collection systems, etc., could be major nonindustrial sources for copper, zinc, and lead. These are just a few examples of nonindustrial sources of heavy metals.

To properly address these nonindustrial sources, the age of the city, amount of combined sewers, inflow and infiltration need to be known. If the collection system is largely combined sewers or if there is a high inflow then precipitation will effect the heavy metal concentration. The data base does have information on combined sewers and inflow/infiltration, however, without rainfall data the value of this information is limited.

SECTION 7

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APPENDIX A

EPA FORMS FOR EVALUATION OF ENVIRONMENTAL MONITORING LABORATORIES

PART 1. GENERAL INFORMATION ABOUT THE LABORATORY

(1). Appropriateness of Organization

	Best Description of Laboratory	Score
___	Responses to questions indicate the organization is as reported, and that its functioning is not so rigid as to interfere with operational requirements.	5
___	Some doubt that organization as described is really followed. Chain-of-command is followed without deviation to the detriment of good performance.	3
___	Serious doubts concerning organization and control of people.	1*

(2). Impairment of Functions

	Best Description of Laboratory	Score
___	Responses generally satisfactory, no real problems in any of these areas. Certainly nothing said that would indicate impairment of laboratory functions.	5
___	Some problems evident in one or two places. These may make it difficult to operate effectively.	3
___	Management problems are obvious in several areas, hard to get help, customers complain, etc., and performance is likely to suffer.	1*

(3) Strength of Management

	Best Description of Laboratory	Score
___	Firm stand taken concerning internal communications and cooperation between groups. Both annual and long-range plans are made and followed. Firm authority	

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	Best Description of Laboratory	Score
(3)	continued. demonstrated without the feeling of an "absolute monarch." Impression given of "wide awake" management.	5
___	Some weaknesses indicated in a few of the items.	3
___	It appears that management is weak - no plans made for the future - little cooperation or internal communications	1*

(4) Objectivity of the Laboratory

	Best Description of Laboratory	Score
___	Responses open and direct - no reason to doubt objectivity.	5
___	Some aspects of relationsips unclear. Objectivity not seriously questioned but some doubts.	3
___	A conflict of interest exists, is clearly apparent in any part of the organization.	1*

(5) Cooperation Obtained

	Best Description of Laboratory	Score
___	All information provided promptly. Cooperative attitude displayed by all personnel. Preliminary questionnaire distributed to proper persons for completion.	5
___	Most information supplied readily. Satisfactory candid responses.	3
___	Important information not provided and difficult to draw out answers. Cooperation of all not evident. Evaluation presented and no plans to make constructive use of the results.	1*

Note: A score of 1, when marked with an asterisk (1*) in any part of the check list must be resolved to the satisfaction of the evaluator before a final score is calculated.

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PART 2. PERSONNEL

(1). Supervisor Training

	Best Description of Laboratory	Score
___	Supervisors have degrees. Sufficient experience in place of degree	5
___	No degree and less than 5 years experience.	3
___	No degree and insufficient experience.	1

(2). Supervisor Experience

	Best Description of Laboratory	Score
___	The supervisors as individuals and as a group are highly trained and experienced	5
___	The supervisors meet general requirements but are week in environmental monitoring work.	3
___	Some of the group appear deficient in training and experience.	1

(3). Job Description

	Best Description of Laboratory	Score
___	There is a good agreement between description and what is done.	5
___	There is some agreement between description and what is done but considerable deviation.	3
___	General agreement only.	

(4). Training Program

	Best Description of Laboratory	Score
___	Formal training program exists and is followed.	5
___	No formal training program but obviously some training is continued.	3
___	Little evidence that training is done.	1

(5). Turnover Rate

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(5). continued.

Best Description of Laboratory	Score
___ Rate is less than 25%.	5
___ Rate is 25-50%.	3
___ Rate is greater than 50%.	1*

(6). General Morale

Best Description of Laboratory	Score
___ Management exhibits real concern for individuals, Evidenced by central records kept for each individual showing advancement dates, promotions, training programs taken, participation in health programs. General morale of personnel is high.	5
___ No formal central records are maintained but some effort made to encourage people. No evidence of serious morale problems.	3
___ Little concern demonstrated for individuals. Morale problems are evident.	1

PART 3. LABORATORY SPACE AND FACILITIES

(1). General Characteristics

Best Description of Laboratory	Score
___ General characteristics of laboratory satisfactory.	5
___ Impression of laboratory is only average.	3
___ General features of the laboratory are poor.	1

(2) Office Space

Best Description of Laboratory	Score
___ $16.7m^2$ (180 sq. ft) or greater/person.	5
___ $12.5-16.7m^2$ (135-180 sq.ft.)/person.	3
___ Less than $12.5m^2$ (135 sq. ft.)/person.	1

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(3). Laboratory Space

Best Description of Laboratory	Score
___ $18.6m^2$ (200 sq. ft.) or greater/person.	5
___ 13.9-$18.6m^2$ (150-200 sq. ft.)/person.	3
___ Less than $13.9m^2$ (150 sq. ft.)/person	1*

(4). Bench-top Space

Best Description of Laboratory	Score
___ 1.2m (4 lin. ft.) or greater/person	5
___ 0.9_1.2m (3-4 lin. ft.)/person.	3
___ Less than 0.9m (3 lin. ft.)/person.	1

(5). Hood Space Operation

Best Description of Laboratory	Score
___ Hoods sufficient in number and capability.	5
___ Some additional hoods and/or capacity needed.	3
___ Hoods inadequate for purpose intended.	1

(6). Storage Space Chemicals, Reagents, Glassware, Supplies†

Best Description of Laboratory	Score
___ Storage space adequate, accessible and kept orderly.	5
___ Storage space available but overtaxed.	3
___ Storage space insufficient.	1

(7). Sample Storage††

Best Description of Laboratory	Score
___ Sample storage space is adequate and necessary provisions are made for samples requiring special attention.	5
___ Sample storage satisfactory in general but some special requirements are not fully met.	3
___ Sample storage space inadequate and inefficiently arranged.	1

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(8). Controlled Space

	Best Description of Laboratory	Score
___	Controlled space necessary for performance of services offered by the laboratory is available. Responsibility for operation of these rooms is assigned and continuous check of conditions is maintained.	5
___	Necessary rooms are available but control is slack and checks are made only daily.	3
___	There are unsatisfactory needs for control space and/or responsibility is not well defined and checking is less frequent than daily.	1

†Note: Further questions about inventory policy and materials identification are asked in Part 6.

††Note: Further questions about control of samples appear in Part 6.

(9). Library

	Best Description of Library.	Score
___	A library is available; it is easily accessible, orderly, and well looked after.	5
___	There is a library but it is disorganized and difficult to use.	3
___	No organized library exists and each section or staff member keeps own references, periodicals, etc.	1

(10). Safety Equipment and Procedures

	Best Description of Laboratory.	Score
___	Safety equipment is available, regulations are posted, and regular drills are held.	5
___	Safety equipment is good but improvements in the lab safety program are needed.	3
___	Safety equipment is not complete and an effective program does not exist.	1

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(11). Distilled Water/Deionized Water

	Best Description of Laboratory	Score
___	Apparatus and water checked every day and kept in proper condition by one designated individual who keeps a record.	5
___	Greater interval than one day between checks by designated individual	3
___	No one person responsible and no written procedure or records maintained.	1*

(12). Glassware Supply and Washing

	Best Description of Laboratory	Score
___	Glassware supply and washing are satisfactory in all respects.	5
___	More attention needs to be given to washing equipment or procedures.	3
___	Careless job done of glassware washing.	1

(13). Housekeeping

	Best Description of Laboratory	Score
___	Laboratory has clean, neat appearance; movement and work are not impeded by clutter.	5
___	Laboratory is clean but not as neat as should be expected.	3
___	Poor housekeeping evident by dirt or clutter.	1

(14). Data Processing Equipment and Logistic Services

	Best Description of Laboratory	Score
___	Communication facilities within and outside the laboratory good. Computing capability present.	5
___	Communications within and outside laboratory are limited. Data processing facilities inconvenient to use.	3
___	Laboratory and sections thereof are isolated and computing capability sufficient for timely results not available.	1

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PART 4. ANALYTICAL METHODS

(1). Reference Methods or Approved Alternates

	Best Description of Laboratory	Score
___	All methods used are Federal Register referenced methods or specific EPA aproval has been obtained.	5
___	Some easily correctable minor deviations from referenced methods exist and steps are being taken to conform to standards.	3
___	Some nonstandard methods which do not have specific EPA approval are in use.	1*

(2). Reagent and Media Preparation

	Best Description of Laboratory	Score
___	Laboratory personnel are clearly aware of the importance of proper preparation, use, and storage of reagents and media, and laboratory procedures and practices are adequate to ensure same.	5
___	Although personnel awareness and laboratory procedures regarding preparation, use, and storage of reagents and media are generally satisfactory, one or two examples of improper preparation, careless use, improper storage (time, temperature, container, etc), inadequate records, or other unacceptable procedures or attitudes were noted.	3
___	Personnel attitudes and/or laboratory procedures for ensuring proper preparation, use, and storage of reagents and media are not adequate.	1

(3). Performance According to Standard

	Best Description of Laboratory	Score
___	Performance of analysis is closely supervised and all testing conforms to standards.	5
___	The laboratory does not have a specific control program for each sampling procedure and analytical test and performance is uneven.	3
___	Supervision of the analysts is lax and confusion exists about specific details on some control procedures.	1

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PART 5. ANALYTICAL INSTRUMENTS

(1). Required Instrumentation

	Best Description of Laboratory	Score
___	All required instrumentation is in good working order.	5
___	Some instrumentation is of doubtful quality or is in some degree of desrepair.	3
___	Needed items of equipment are missing, are not adequate for satisfactory work, or are improperly maintained.	1

(2). Function Tests and Standardization of Instruments

	Best Description of Laboratory	Score
___	Instruments are maintained operative, accurate, and precise by regular functioning checks and by use of standard before unknown samples. Standard curves are available wherever indicated.	5
___	Instruments are periodically checked against zero point or other reference and examined for evidence of physical were or inadequate maintenance.	3
___	Instruments are checked only when they stop working or when excessive difficulties are experienced.	1

(3). Calibration Equipment

	Best Description of Laboratory	Score
___	Necessary calibration equipment is available and in good working condition.	5
___	Calibration equipment is of doubtful quality or is in some degree of disrepair.	3
___	Needed items for calibration are missing, are not adequate for precise work, or are improperly maintained.	1

PART 6. INTERNAL AND EXTERNAL CONTROLS

1. Control of Analytical Methods and Instruments.

(1). Assignment of Responsibility for maintenance and Calibration.

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(1). continued.

Best Description of Laboratory	Score
___ Responsibility is clearly assigned in this laboratory and understood by all personnel.	5
___ Responsibility is assigned but not clearly recognized or understood by assignee(s) or other personnel.	3
___ Responsibility is not clearly assigned or recognized in this laboratory.	1

(2). Maintenance and Calibration Logs

Best Description of Laboratory	Score
___ The instrment logs are properly executed, complete, and up-to-date.	5
___ An instrument log exists but is faulty.	3
___ An instrument log does not exist.	1

(3). Adequacy of Calibration and Maintenance Practices

Best Description of Laboratory	Score
___ Calibration and maintenance of instruments is adequate.	5
___ Marginal.	3
___ Inadequate.	1*

2. Control of Sampling.

(4). Sampling Plans and Sampling Equipment.

Best Description of Laboratory	Score
___ Samples are carefully designed, suitable sampling equipment is on hand and is used properly.	5
___ Sampling is taken for granted and no particular efforts are made to assure validity of samples.	3
___ Sampling is not organized, equipment is poor, or insufficient care is taken in obtaining the samples.	1

(5). Sample Collection and Preservation

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(5). continued.

	Best Description of Laboratory	Score
___	Samples are kept in proper containers using the recommended preservative for no longer than the recommended maximum holding time.	5
___	When possible, the recommended procedures for collection and preservation are followed, although circumstances (laboratory manpower, lack of control over sample taking, variability of workload, etc.), do not always allow strict adherence.	3
___	The laboratory often does not follow EPA recommendations for maximum holding time, preservation technique, and/or container type.	1

(6). Identification and Storage of Samples

8-1/2"

	Best Description of Laboratory	Score
___	Samples are carefully and clearly identified by code number and stored so as to protect their identity and security.	5
___	Sample identification system and storage of samples not well organized.	3
___	There are serious defects in sample identification and storage of samples not well organized.	1

(7). Laboratory handling of Samples

	Best Description of Laboratory	Score
___	Activities of the laboratory are well organized so that samples are given the attention required and work proceeds smoothly from sample receipt to report of results.	5
___	Procedures for assuring smooth flow of samples through The laboratory are not complete.	
___	The system and load are not well matched so that there is a backlog of work and time requirements are sometimes missed.	1

(8). Chain of Custody

	Best Description of Laboratory	Score

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(8). continued

___	A chain of custody procedure is followed precisely, with clearly assigned responsibility, complete recording of activities, and careful security of samples.	5
___	A chain of custody procedure exists but it is lax and not strictly followed.	
___	Chain of custody is not formally organized.	1*

(9). Control of Field Sampling/Measurements[†]

	Best Description of Laboratory	Score
___	Written procedures for field sampling/measurements are complete and are followed meticulously under surveillance by the laboratory.	5
___	Field sampling/measurement are subject to standard methods but surveillance by the laboratory is lax.	3
___	Field sampling/measurement is not treated as a major concern of the laboratory.	1

(10). Control of Monitoring[††]

	Best Description of Laboratory	Score
___	Written procedures which are followed exactly are available for all monitoring activities in which this laboratory is engaged.	5
___	Written procedures exist but they are incomplete and not followed exactly.	3
___	No written procedures exist.	1

[†] Note: If the laboratory does not participate in this activity, do not score it and subtract 5 from the denominator of the fraction in the formula for caculating its score for internal and external controls.

[††] Note: If the laboratory does not participate in this activitiy, do not score it and subtract 5 from the denominator of the fraction in the formula for calculating its score for internal and external and external controls.

3. Quality Control.

(11). Quality Policy

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(11). continued

	Best Description of Laboratory	Score
___	A clear statement of the quality objectives by the top executive exists with continuing visible evidence of its sincerity to all levels of the organization.	5
___	Periodic meetingsamong the section heads of service, research and development, and quality assurance are held to discuss quality objectives and progress toward their achievement.	3
___	There is "one-shot" statement of the desire for product quality by the top executive after which the quality control staff is on its own.	1

(12). Quality Program Manual

	Best Description of Laboratory	Score
___	Formalized and documented by a set of procedures which clearly describe the activities necessary and sufficient to achieve desired quality objectives. This may be in the form of a Quality Control Manual.	5
___	The Quality Program is contained in methods procedures or is implicit inthese procedures, Experience with the materials, product and equipment is needed for continuity of control.	3
___	The Quality Program is undefined in any procedures and is left to the current managers or supervisors to determine as the situation dictates.	1*

(13). Responsibility for Quality

	Best Description of Laboratory	Score
___	Responsibility for quality is a full-time assignment of a quality control department with well-defined authority or in smaller laboratories is clearly defined for all sections and section chiefs.	5
___	Responsibility for quality is assigned to a part-time quality control coordinator who must use whatever means possible to achieve quality goals.	3
___	Responsibility for quality is not defined.	1*

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(14). Training for Quality Control

	Best Description of Laboratory	Score
___	The people who have an impact on quality (bench chemists, supervisors, etc.) are trained in the reasons for and the benefits of standards of quality and the methods by which high quality can be achieved.	5
___	Personnel are told about quality only when their work falls below acceptable levels.	3
___	Personnel are reprimanded when quality deficiencies are directly traceable to the chemist's analytical work.	1

(15). Control of Chemicals and Reagents

	Best Description of Laboratory	Score
___	Reagents and chemicals are inspected upon receipt and accepted only if they conform to all specifications. In inventory they are identified as to type and age and issued on a first in/first out plan.	5
___	Reagents and chemicals are only spot checked for quantity and shipping damage; in storage they are identified as to material only and are issued randomly.	3
___	Reagents and chemicals are not checked on receipt, are not clearly identified, and are issued on a last in/first out basis.	1

(16). Intralaboratory Checks - Precision and Accuracy

	Best Description of Laboratory	Score
___	Laboratory has a well-organized program to check the validity of data it produces.	5
___	Incomplete information is available on precision and accuracy of the tests in use.	3
___	Laboratory has no plan to check on validity of its data.	1

(17). Routine Checks of Testing Performance

	Best Description of Laboratory	Score
___	Procedures are excellent and should provide adequate	

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	assurance that the data are valid.	5
___	Procedures are fair and should provide some indication of the validity of the data.	3
___	Procedures are poor or poorly defined and do not provide adequate assurance that the data are valid.	1*

(18). Statistical Methods

	Best Description of Laboratory	Score
___	Use is made of statistical methods, such as control charts to insure continuing validity of tests.	5
___	Some statistical checks of measurements are made but level of assurance of quality is uncertain.	3
___	No efforts are made to use statistical methods of quality control.	1

(19). Interlaboratory Proficiency Tests

	Best Description of Laboratory	Score
___	The laboratory has a good record of participation in formal proficiency testing and has a good record of performance.	5
___	Laboratory participants only sporadically and not recently. Performance in programs not outstanding.	3
___	Laboratory does not participate in proficiency testing programs.	1*

(20). Laboratory Records

	Best Description of Laboratory	Score
___	Analytical results are entered in a lab notebook or in a card system which is signed and witnessed. Results are summarized and entered in appropriate data system promptly.	5
___	Analytical results are complete but they are not routinely signed and witnessed. Data processing is not always prompt.	3

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___	Data keeping is not organized, i.e., results kept on loose sheets of paper and incompletely reviewed and analyzed.	1

(21). Laboratory Reports

	Best Description of Laboratory	Score
___	Lab activities are reported regularly and periodic quality reports are made to feed forward to management and to feed back to bench analysts quality of the work reported.	5
___	Laboratory reports are sporadic and quality reports do not result in bringing necessary information for action on quality to all levels of the organization.	5
___	Reports are very irregular and no system for quality reporting exists.	1

SUMMARY OF LABORATORY EVALUATION

NAME OF LABORATORY____

		Score
Part 1.	General Information	
Part 2.	Personnel	
Part 3.	Lab Space and Facilities	
Part 4.	Technical Services (Analytical Methods)	
Part 5.	Lab Equipment	
Part 6.	Internal and External Controls	
	Total	_____

Inadequacies marked by * in the score sheets have not been resolved and the above is a tentative score. ()

Final Score____________

Date:____________________________ Evaluation Completed by:______________

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APPENDIX B

LABORATORY RATING FORMS DEVELOPED FOR METALS ANALYSIS LABORATORIES

PART 1. PERSONNEL AND INTERNAL AND EXTERNAL CONTROLS (0)

(1). Supervisor Experience

___ Supervisors have degrees. Sufficient experience in place of degree.

___ No degree and less than 5 years experience.

___ No degree and insufficient experience.

(2). Analyst Experience

___ The analysts as individuals and as a group are highly trained and experienced.

___ The analysts meet general requirements but are weak in environmental monitoring work.

* ___ Some of the group appear deficient in training and experience.

(3). Training Program

___ Formal training program exists and is followed.

___ No formal training prgram but obviously some training is continued.

___ Little evidence that training is done.

(4). Turnover Rate

___ Average tenure 1 yr. of AA technician.

___ Average tenure ½ - 1 yr., or instrument personnel rotate.

* ___ Average tenure ½ yr. or lab personnel rotate.

(5). Function Tests and Standardization of Instruments

___ Instruments are maintained operative, accurate, and precise by regular functioning checks and by use of standard before unknown samples. Standard curves are available wherever indicated.

___ Instruments are periodically checked against zero point or other reference and examined for evidence of physical wear or inadequate maintenance.

___ Instruments are checked only when they stop working or when excessive difficulties are experienced.

(Instrument description: Model________________Age___________)

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(6). Calibration Equipment

___ Necessary calibration equipment is available and in good working condition.

___ Calibration equipment is of doubtful quality or is in some degree of disrepair.

___ Needed items for calibration are missing, are not adequate for precise work, or are improperly maintained.

(Calibration stock description:________________________)

(7). Assignment of Responsibility for Maintenance and Calibration

___ Responsibility is clearly assigned in this laboratory and understood by all personnel.

___ Responsibility is assigned but not clearly recognized or understood by assignee(s) or other personnel.

___ Responsibility is not clearly assigned or recognized in this laboratory.

(8). Maintenance and Calibration Logs

___ The instrument logs are properly executed, complete, and up-to-date.

___ An instrument log exists but is faulty.

___ An instrument log does not exist.

(9). Performance According to Standard

___ Performance of analysis is closely supervised and all testing conforms to standards.

___ The laboratory does not have a specific control program for each sampling procedure and analytical test and performance is uneven.

___ Supervision of the analysis is lax and confusion exists about specific details of some control procedures.

(10). Sampling Plans and Sampling Equipment

___ Samples are carefully designed, suitable sampling equipment is on hand and is used properly.

___ Sampling is taken for granted and no particular efforts are made to assure validity of samples.

___ Sampling is not organized, equipment is poor, or insufficient care is taken in obtaining the samples.

(11). Sample collection and preservation

___ Samples are kept in proper containers using the recommended preservative for no longer than the recommended maximum holding time.

___ When possible, the recommended procedures for collection and preservation are followed, although circumstances (laboratory manpower, lack of control over sample taking, variability of workload, etc.) do not always allow strict adherence.

___ The laboratory often does not follow EPA recommendations for maximum holding time preservation technique, and/or container type.

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(12). Chain of Custody

___ A chain of custody procedure is followed precisely, with clearly assigned responsibility, complete recording of activities, and careful security of samples.

___ A chain of custody procedure exists but it is lax and not strictly followed.

* ___ Chain of custody is not formally organized.

(13). Control of Field Sampling/Measurements

___ Written procedures for field sampling/measurements are complete and are followed meticulously under surveillance by the laboratory.

___ Field sampling/measurement are subject to standard methods but surveillance by the laboratory is lax.

___ Field sampling/measurement is not treated as a major concern of the laboratory.

(14). Control of Monitoring

___ Written procedures which are followed exactly are available for all monitoring activities in which this laboratory is engaged.

___ Written procedures exist buy they are incomplete and not followed exactly.

___ No written procedures exist.

(15). Quality Policy

___ A clear statement of quality objectives by the top executive exists with continuing visible evidence of its sincerity to all levels of the organization.

___ Periodic meetings among the section heads of service, research and development, and quality assurance are held to discuss quality objectives and progress toward their achievement.

___ There was a "one-shot" statement of the desire for product quality by the top executive after which the quality control staff is on its own.

(16). Quality Program Manual

___ Formalized and documented by a set of procedures which clearly describe the activities necessary and sufficient to achieve desired quality objectives. This may be in the form of Quality Control Manual.

___ The Quality Program is contained in methods procedures or is implicit in those procedures. Experience with the materials, product and equipment is needed for continuity of control.

* ___ The Quality Program is undefined in any procedures and is left to the current managers or supervisors to determine as the situation dictates.

(17). Responsibility for Quality

___ Responsibility for quality is a full-time assignment of a quality control department with well-defined authority or in smaller laboratories is clearly defined for all sections and

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section chiefs.
___ Responsibility for quality is assigned to a part-time quality control coordinator who must use whatever means possible to achieve quality goals.
* ___ Responsibility for quality is not defined.

(18). Training for Quality Control
___ The people who have an impact on quality (bench chemists, supervisors, etc.) are trained in the reasons for and the benefits of standards of quality and the methods by which high quality can be achieved.
___ Personnel are told about quality only when their work falls below acceptable levels.
___ Personnel are reprimanded when quality deficiencies are directly traceable to the chemist's analytical work.

(19). Control of Chemicals and Reagents
___ Reagents and chemicals are inspected upon receipt and accepted only if they conform to all specifications. In inventory they are identified as to type and age and issued on a first in/first out plan.
___ Reagents and chemicals are only spot checked for quantity and shipping damage; in storage they are identified as to material only and are issued randomly.
___ Reagents and chemicals are not checked on receipt, are not clearly identified, and are issued on a last in/first out basis.

(20). Intralaboratory Checks - Precision and Accuracy
___ Laboraty has a well-organized program to check the validity of data it produces.
___ Incomplete information is available on precision and accuracy of the tests in use.
___ Laboratory has no plan to check on validity of its data.

(21). Routine Checks of Testing Performance
___ Procedures are excellent and should provide adequate assurance that the data are valid.
___ Procedures are fair and should provide some indication of the validity of the data.
* ___ Procedures are poor or poorly defined and do not provide adequate assurance that the data are valid.

(22). Statistical Methods
___ Use is made of statistical methods, such as control charts to insure continuing validity of tests.
___ Some statistical checks of measurements are made but level of assurance of quality is uncertain.
___ No efforts are made to use statistical methods of quality control.

(23). Interlaboratory Proficiency Tests
___ The laboratory has good records of participation in formal proficiency testing and has a good record of performance.

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___ Laboratory participates only sporadically and not recently. Performance in programs is not outstanding.

* ___ Laboratory does not participate in proficiency testing prgrams.

PART 2. LABORATORY SPACE AND FACILITIES (L)

(1). Laboratory Space
___ Spacious.
___ Compact.
* ___ Cramped.

(2). Bench-top Space
___ Spacious.
___ Compact.
___ Cramped.

(3). Hood Space and Operation
___ Independent perchloric hood for metals digestion.
___ Proper hood for metals digestion shared for other purposes.
___ No digestion or hoods.

(4). Storage Space Chemicals, Reagents, Glassware, Supplies
___ Storage space adequate, accessible, and kept orderly.
___ Storage space available but overtaxed.
___ Storage space insufficient.

(5). Sample Storage
___ Sample storage space is adequate and necessary provisions are made for samples requiring special attention.
___ Sample storage satisfactory in general but some special requirements are not fully met.
* ___ Sample storage space is inadequate and inefficiently arranged.

(6). Identification and Storage of Samples
___ Samples are carefully and clearly identified by code number and stored so as to protect their identity and security.
___ Sample identification system and storage of samples is not well organized.
* ___ There are serious defects in sample identification and storage practices that could lead to serious mix-ups.

(7). Library
___ A library is available; it is easily accessible, orderly, and well looked after.
___ There is a library, but it is disorganized and difficult to use.
___ No organized library exists and each section of staff members keeps own references, periodicals, etc.

(8). Distilled Water/Deionized Water
___ Deionized water or deionized distilled water with documented metals background/proper replacement schedule for system.

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___ Deionized and/or distilled water system with intermittent documentation

* ___ Distilled water only--no records on background.

(Description of Distilled/Deionized Water System: ______________________________________)

(9). AA Area and Environment

___ Controlled space necessary for performance of services is available. Responsibility for operation of these rooms is assigned and continuous check of conditions is maintained.

___ Necessary rooms are available but control is slack.

* ___ There are unsatisfied needs for controlled space.

(10). Laboratory Handling of Samples

___ Activities of the laboratory are well organized so that samples are given the attention required and work proceeds smoothly from sample receipt to report of results.

___ Procedures for assuring smooth flow of samples through the laboratory are not complete.

___ The system and load are not well matched so that there is a backlog of work and time requirements are sometimes missed.

PART 3. GENERAL INFORMATION ABOUT THE LABORATORY (C)

(1). Objectivity of the Laboratory

___ Responses open and direct - no reason to doubt objectivity.

___ Some aspects of relationsips unclear. Objectivity is not seriously questioned but some doubts.

* ___ A conflict of interest exists, is clearly apparent in any part of the organization.

(2). Cooperation Obtained

___ All information provided promptly. Cooperation attitudes displayed by all personnel. Preliminary questionnaire distributed to proper persons for completion.

___ Most information supplied readily. Satisfactory candid responses.

* ___ Important information not provided and difficult to draw out answers. Cooperation of all not evident. Evaluation presented and no plans to make constructive use of the results.

(3). General Morale

___ General morale of personnel is high.

___ No evidence of serious morale problems.

___ Morale problems are evident.

(4). General Characteristics

___ General characteristics of laboratory satisfactory.

___ Impression of laboratory is only average.

___ General features of the laboratory are poor.

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(5). Glassware Supply and Washing

___ Glassware supply and washing are satisfactory in all respects.
___ More attention needs to be given to washing equipment or procedures.
* ___ Careless job done of glassware washing.

(6). Housekeeping

___ Laboratory has clean, neat appearance; movement and work are not impeded by clutter.
___ Laboratory is clean but not as neat as should be expected.
___ Poor housekeeping evident by dirt or clutter.

(7). Reference Methods or Approved Alternates

___ All methods used are Federal Register referenced methods or specific EPA approval has been obtained.
___ Some easily correctable minor deviations from referenced methods exists and steps are being taken to conform to standards.
* ___ Some nonstandard methods which do not have specific EPA approval are in use.

(8). Reagent and Media Preparation

___ Laboratory personnel are clearly aware of the importance of proper preparation, use, and storage of reagents and media, and laboratory procedures and practices are adequate to ensure same.
___ Although personnel awareness and laboratory procedures regarding preparation, use and storage of reagents and media are generally satisfactory, one or two examples of improper storage (time, temperature, container, etc.), inadequate records, or other unacceptable procedures or attitudes were noted.
___ Personnel attitudes and/or laboratory procedures for ensuring proper preparation, use, and storage of reagents and media are not adequate.

(9). Required Instrumentation

___ All required instrumentation is in good working condition.
___ Some instrumentation is of doubtful quality or is in some degree of disrepair.
* ___ Needed items of equipment are missing, are not adequate for satisfactory work, or are improperly maintained.

(10). Adequacy of Calibration and Maintenance Practices

___ Calibration and maintenance of instruments is adequate.
___ Marginal.
* ___ Inadequate.

(11). Laboratory Records

___ Analytical results are entered in a lab notebook or in a card system which is signed and witnessed. Results are summarized and entered in appropriate data system promptly.
___ Analytical results are incomplete but they are not routinely signed and witnessed. Data processing is not always prompt.

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___ Data keeping is not organized, i.e., results kept on loose sheets of paper and incompletely reviewed and analyzed.

(12). Laboratory Reports

___ Lab activities are reported regularly and periodic quality reports are made to feed forward to management and to feed back to bench analysts quality of the work reported.

___ Laboratory reports are sporadic and quality reports do not result in bringing necessary information for action on quality to all levels of the organization.

___ Reports are very irregular and no system for quality reporting exists.

*--Critical response item.

APPENDIX C

DATA CHARACTERIZATION PLOTS FOR THE COMPOSITED DATA BASE

Data are presented as number of observations in tens (x axis) versus the LQI scores on the y axis. The upper range is for laboratories which failed zero or only 1 critical category. The middle range contains those laboratories failing more than one critical category. The bottom range contains those laboratories for which no LQI was obtained.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 257)

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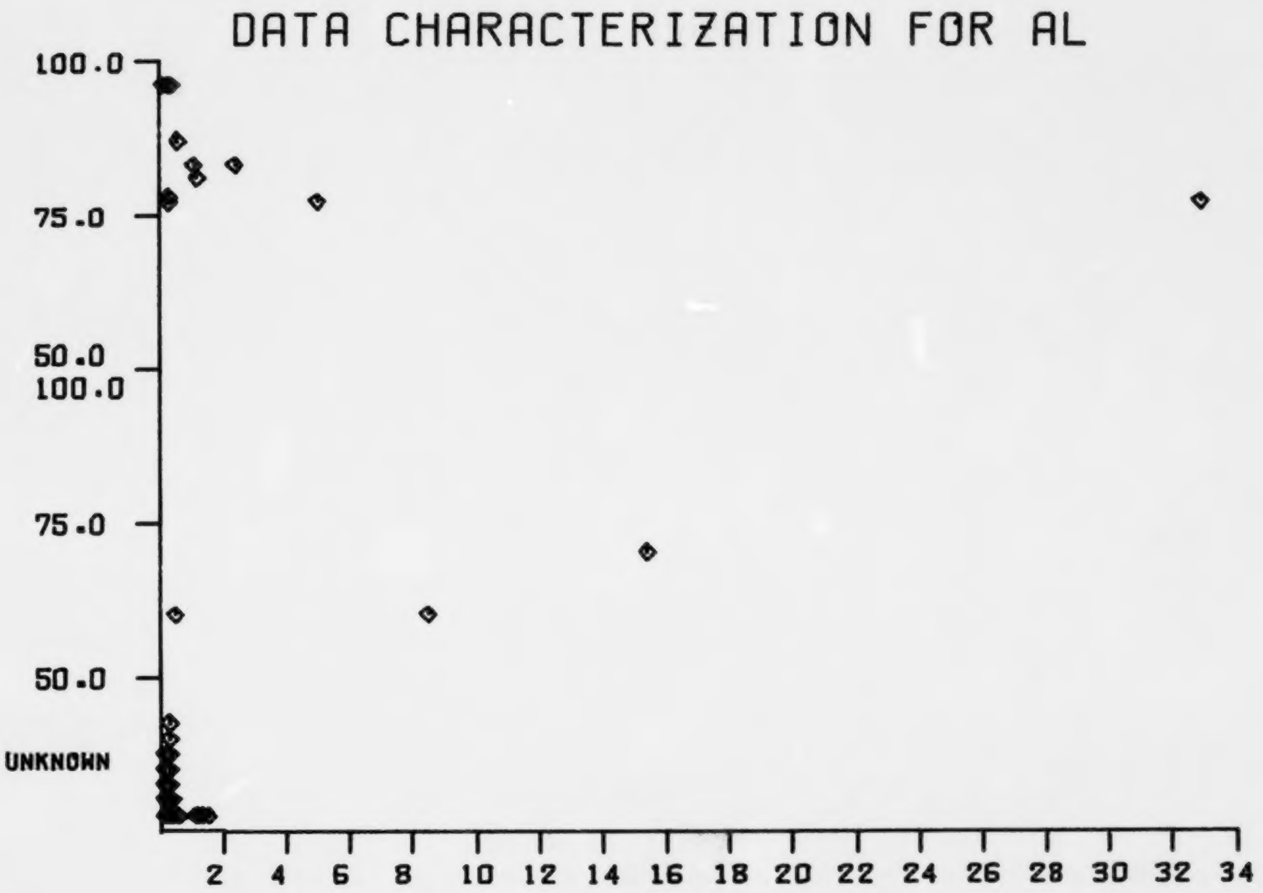
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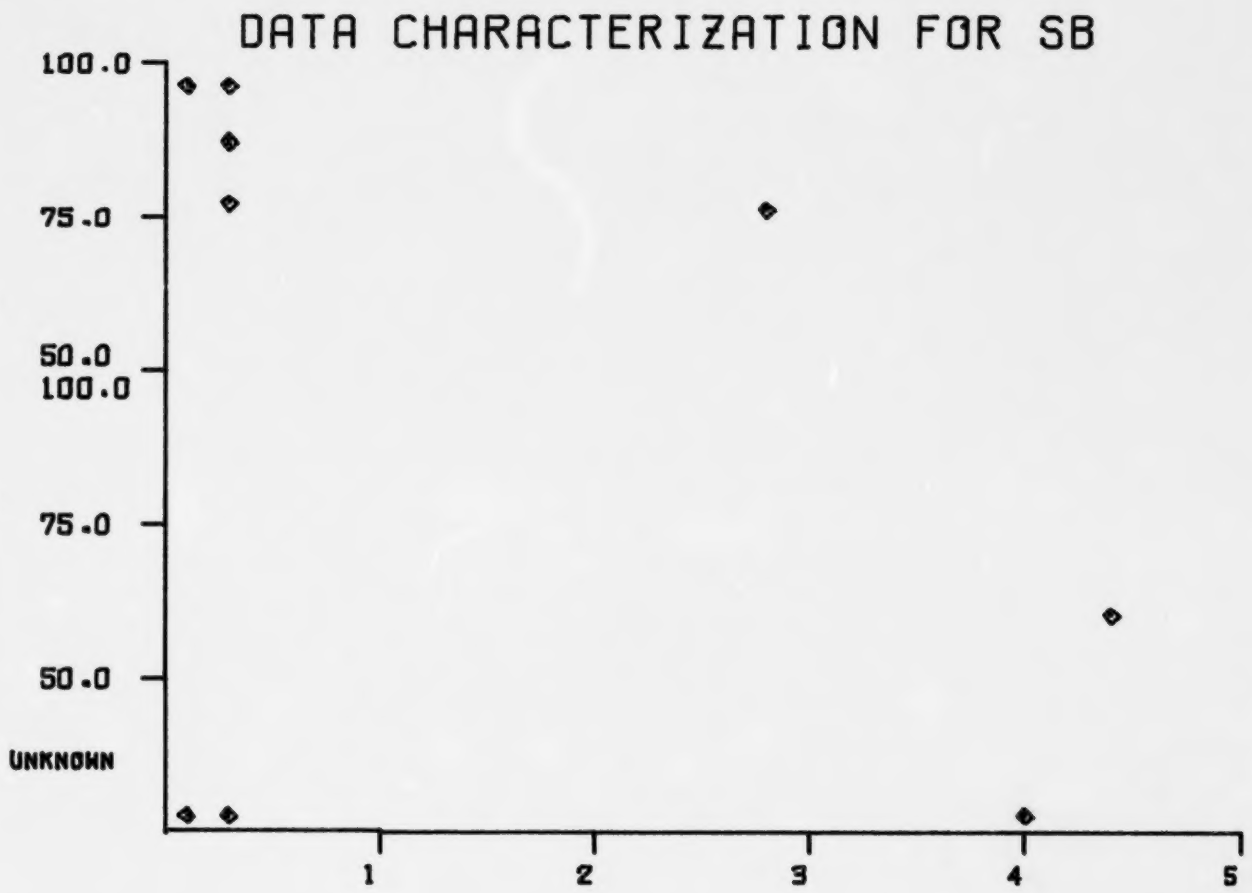
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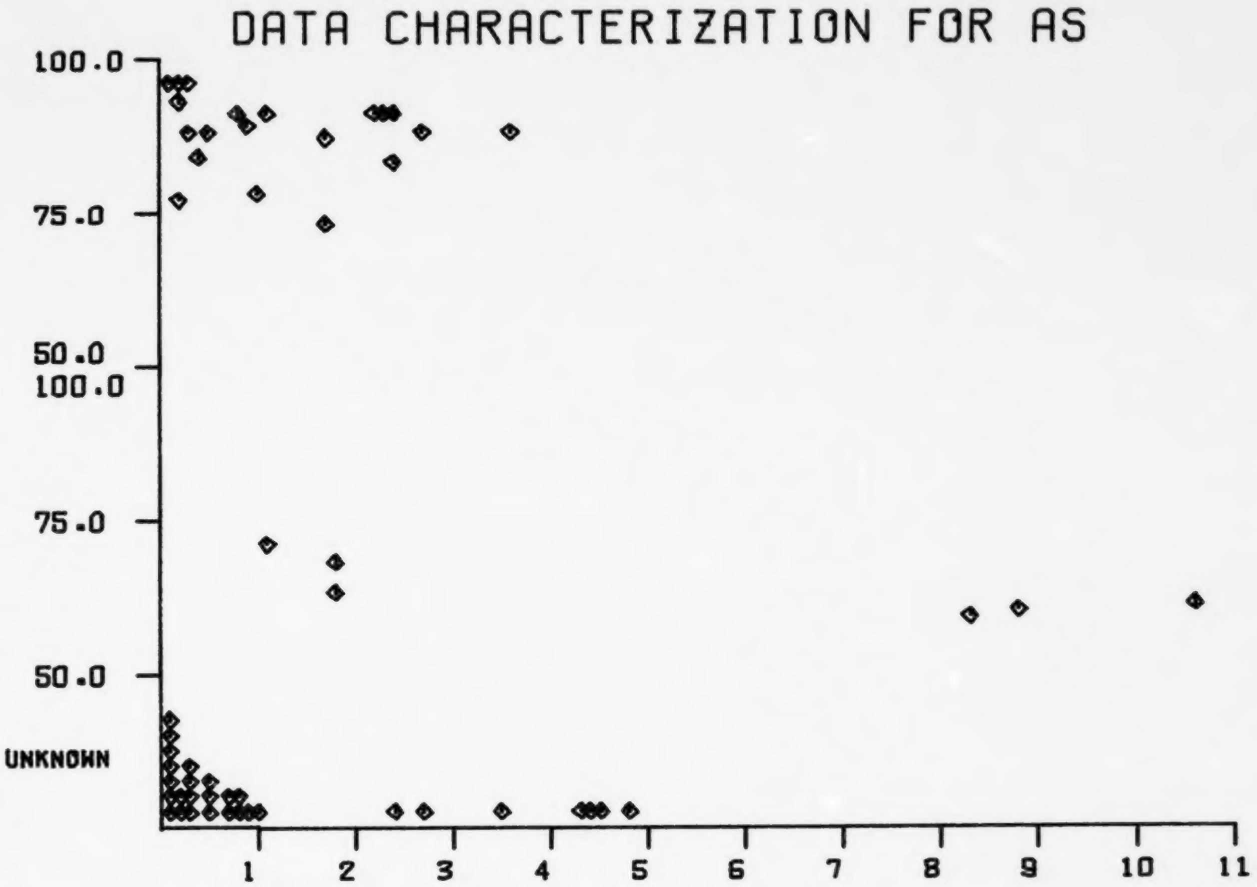
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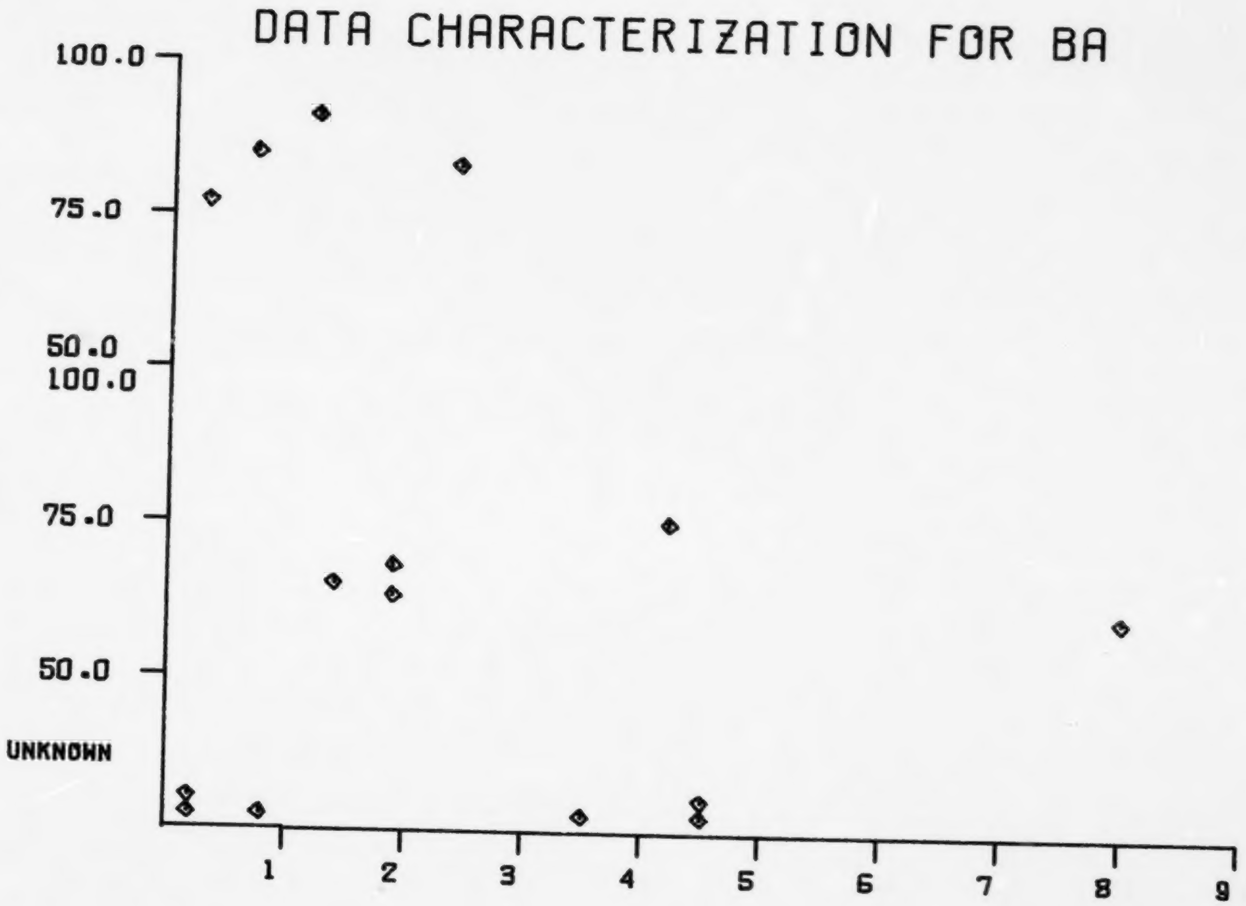
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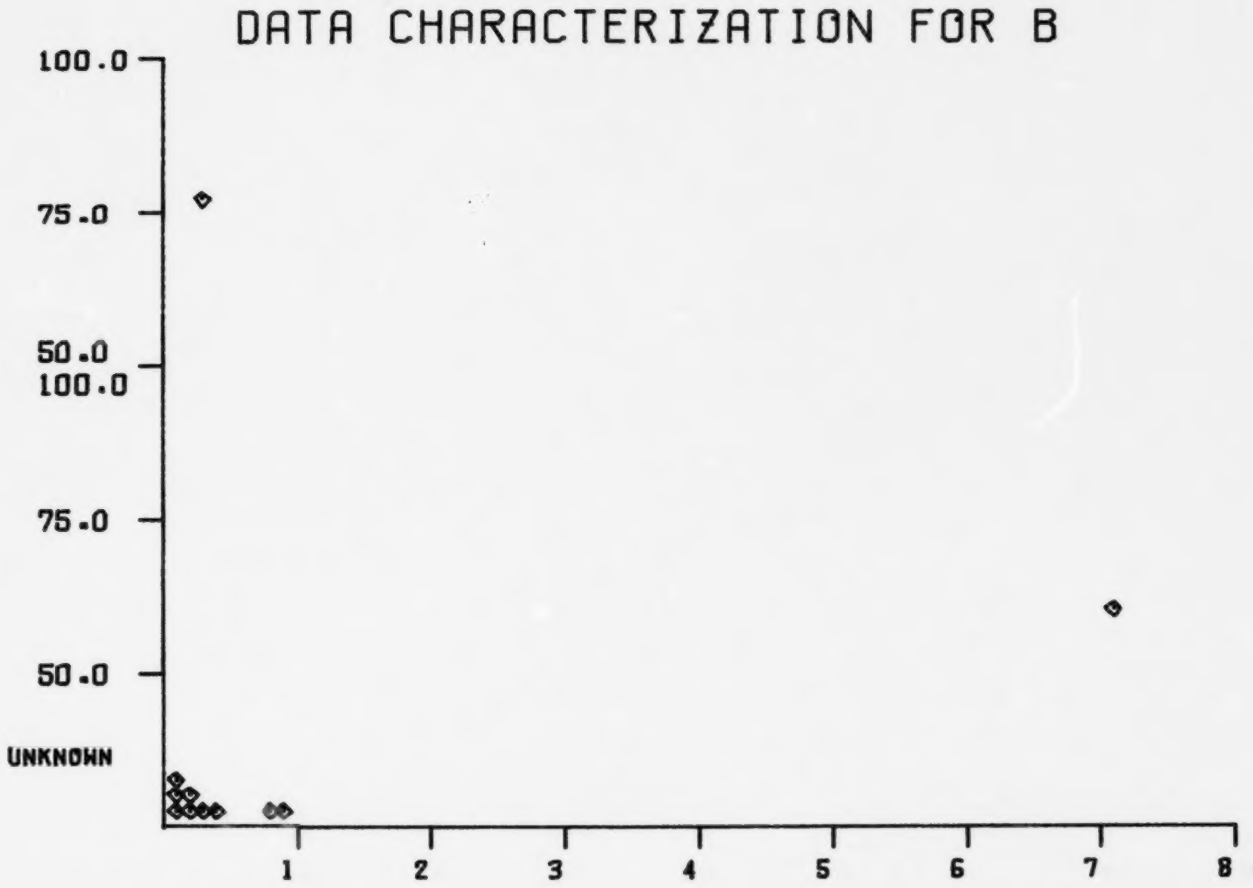
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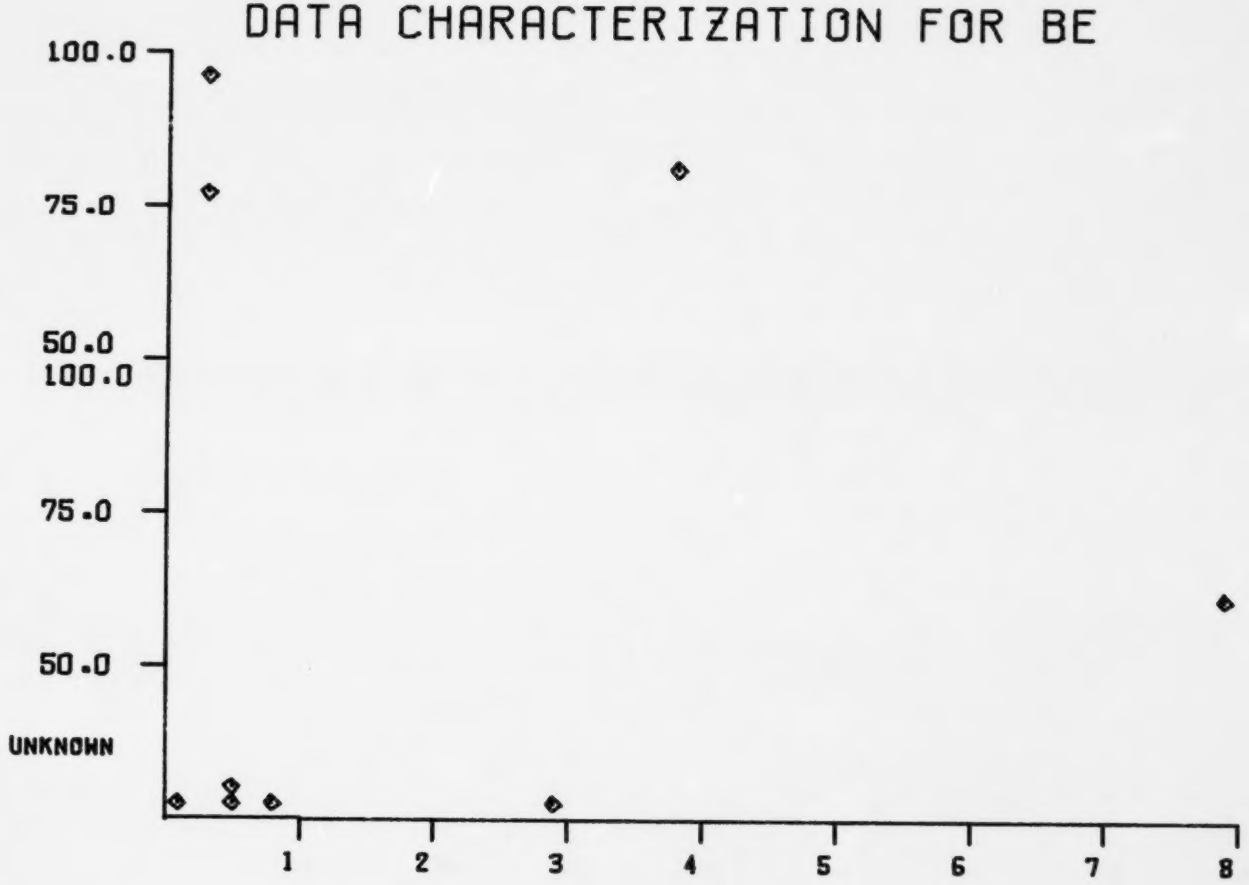
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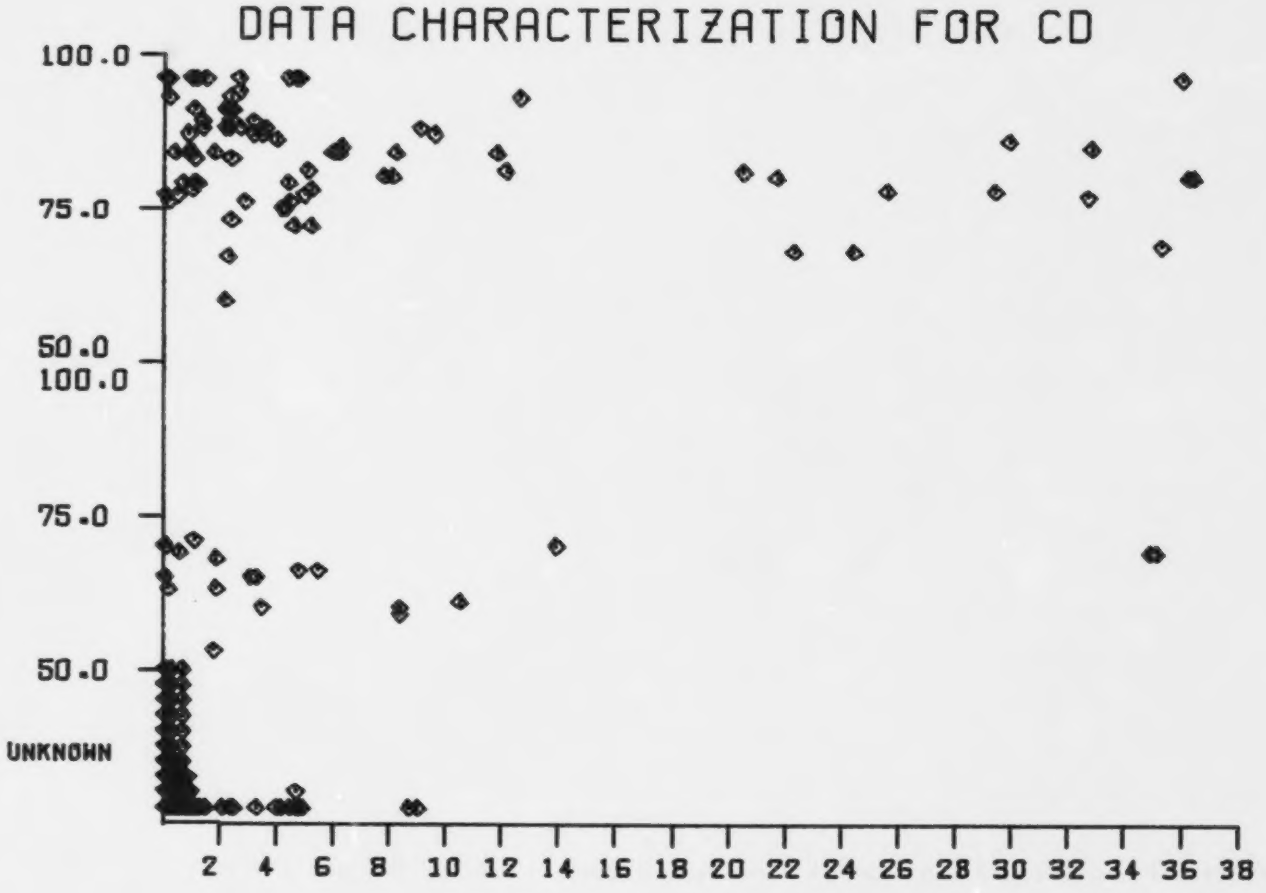
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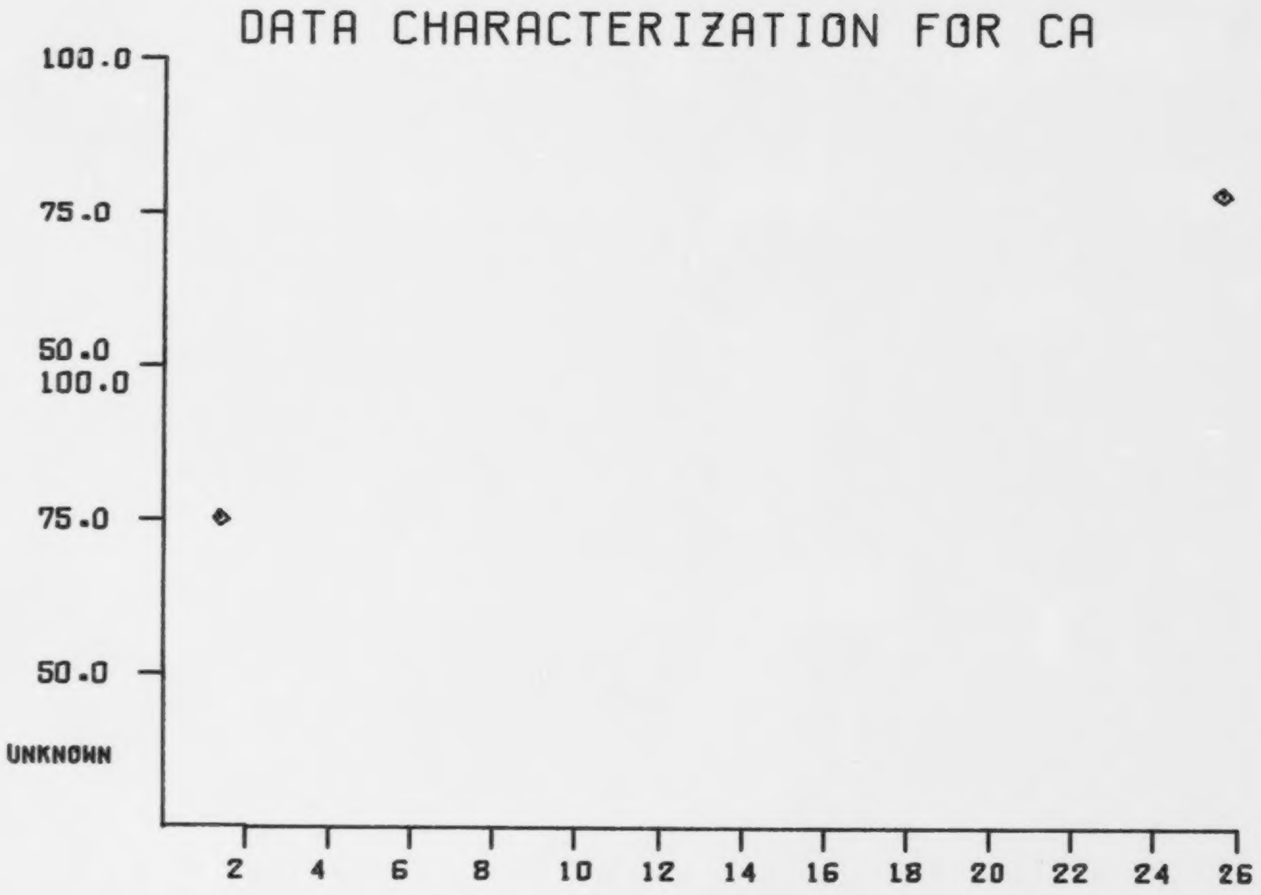
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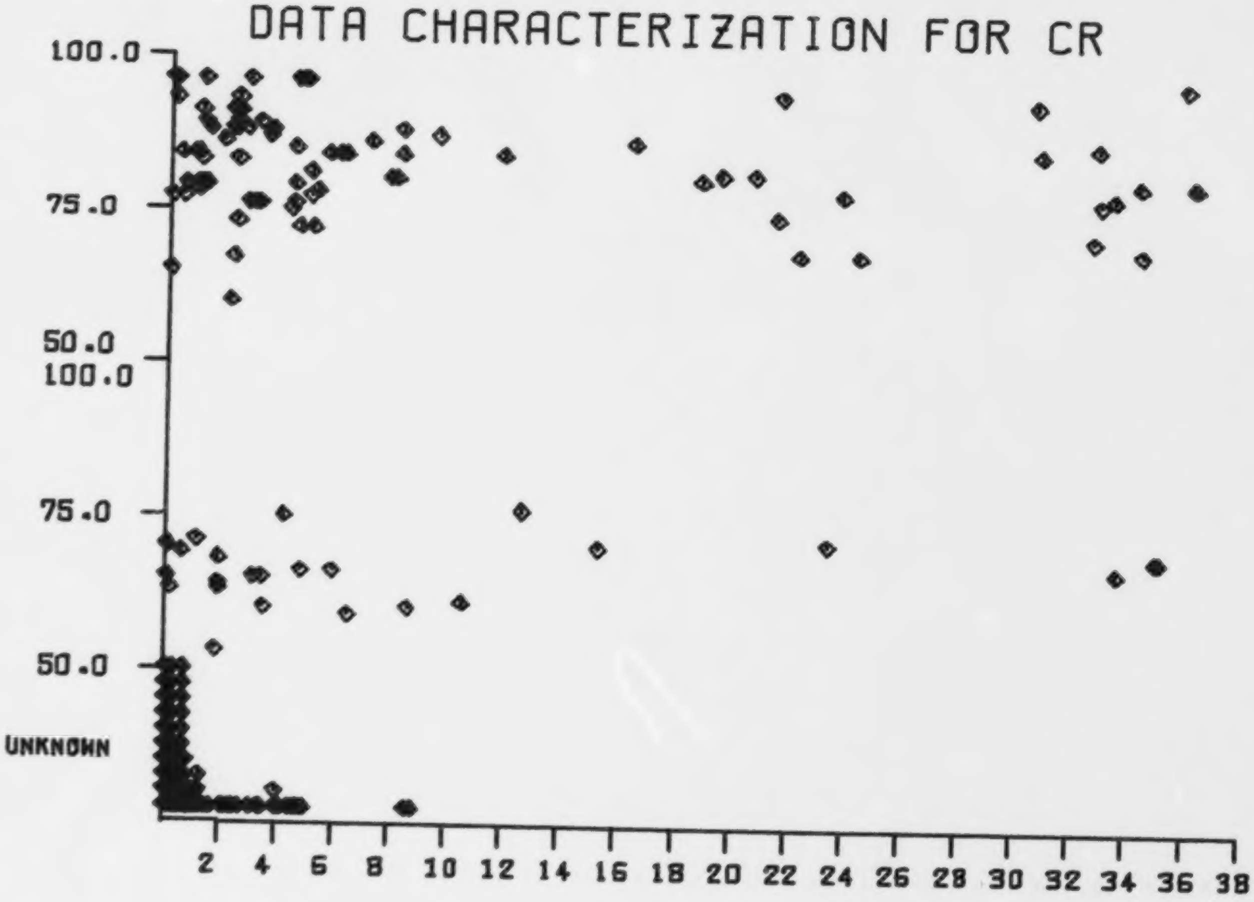
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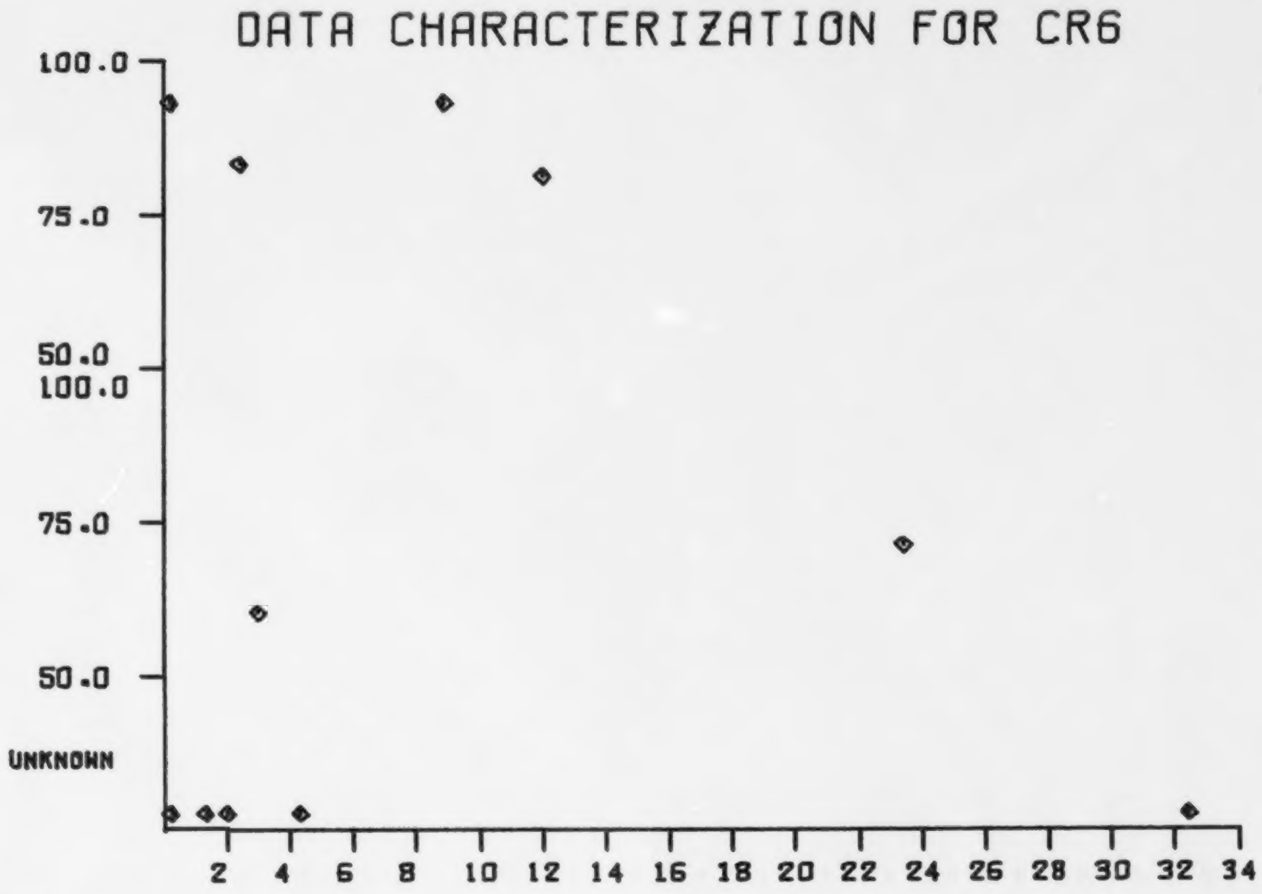
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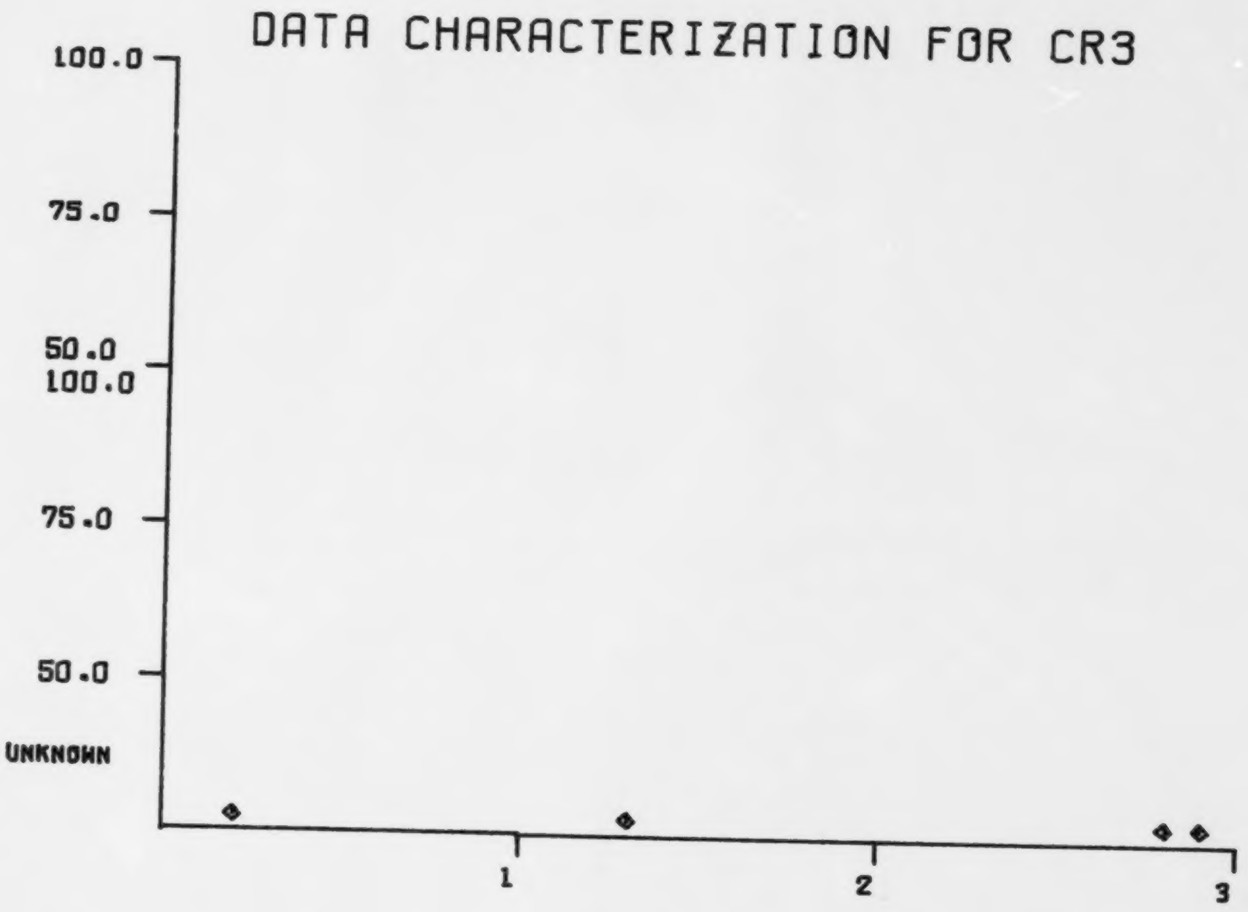
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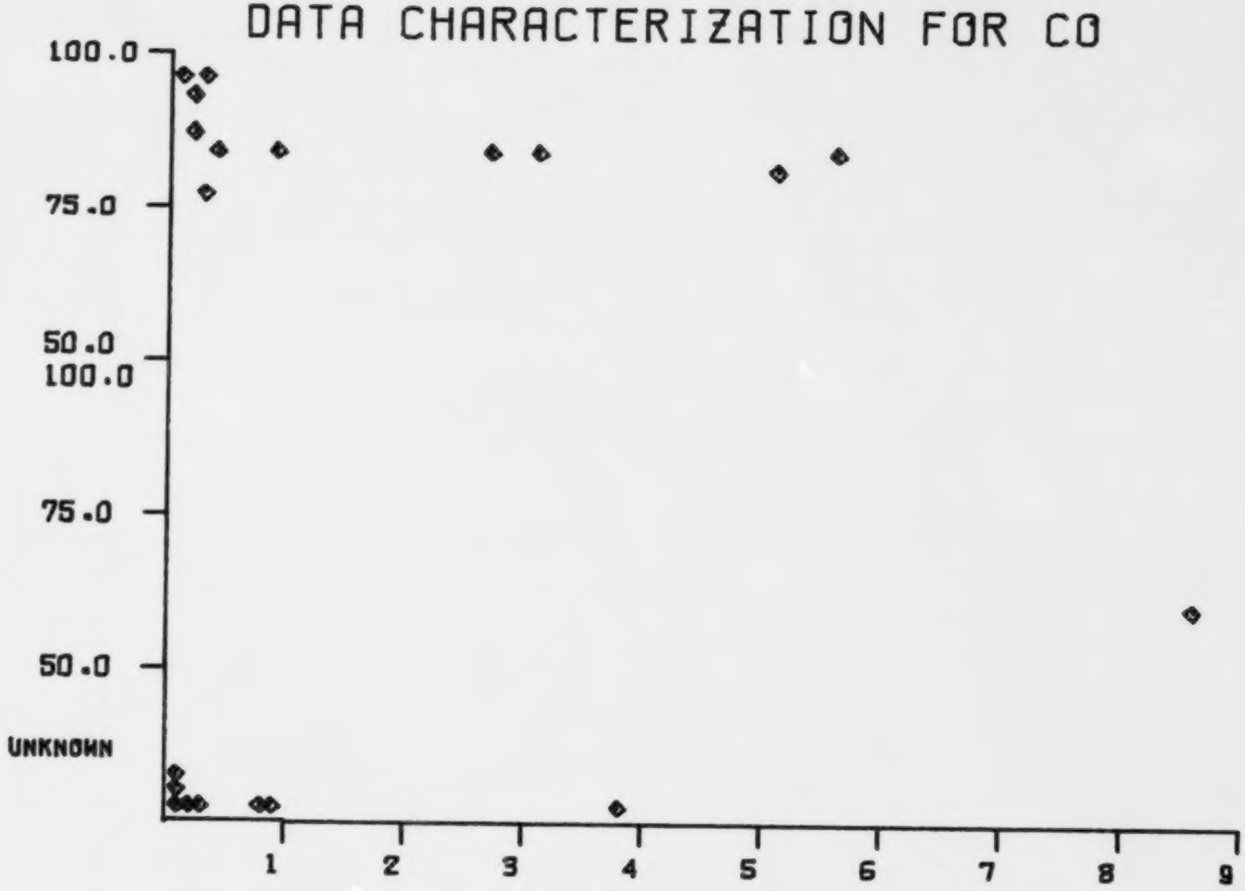
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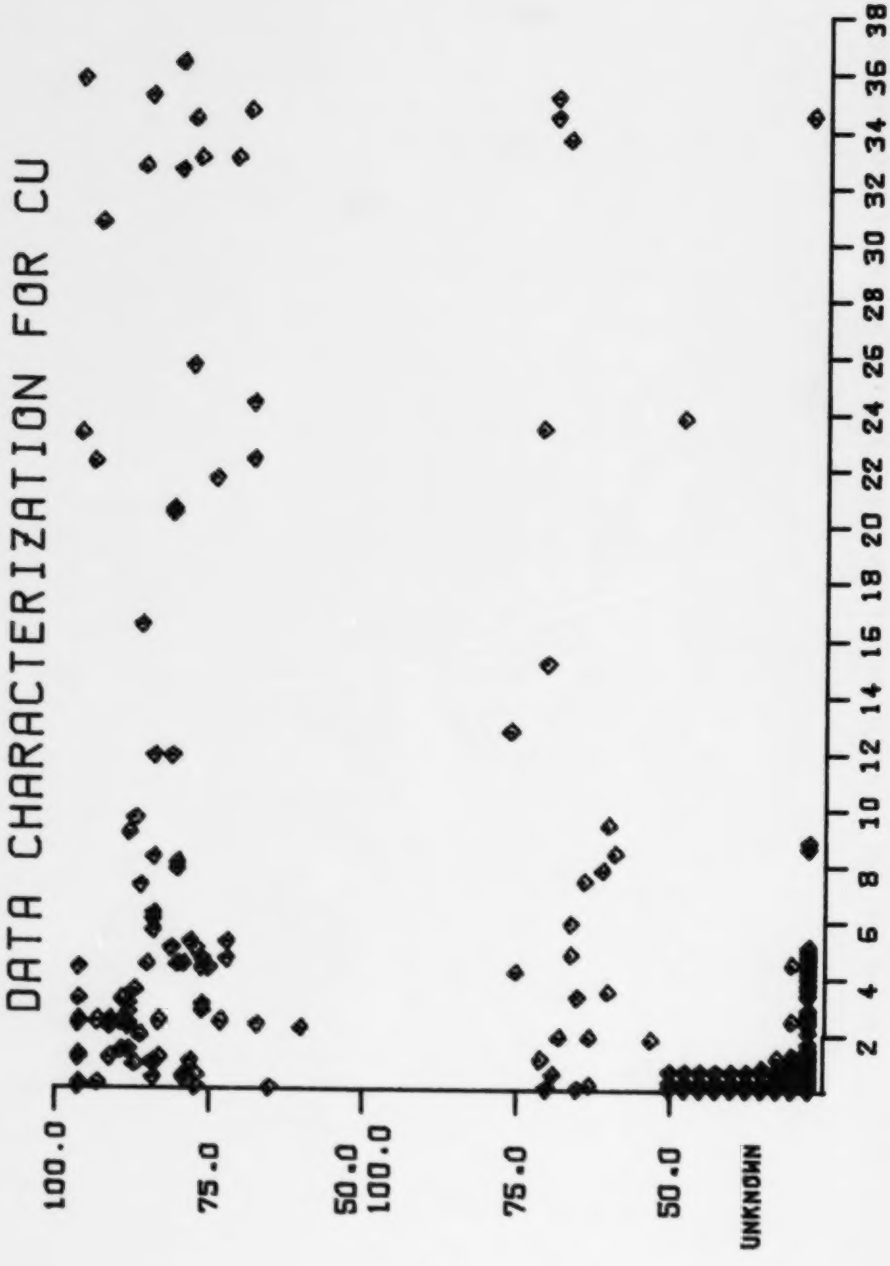
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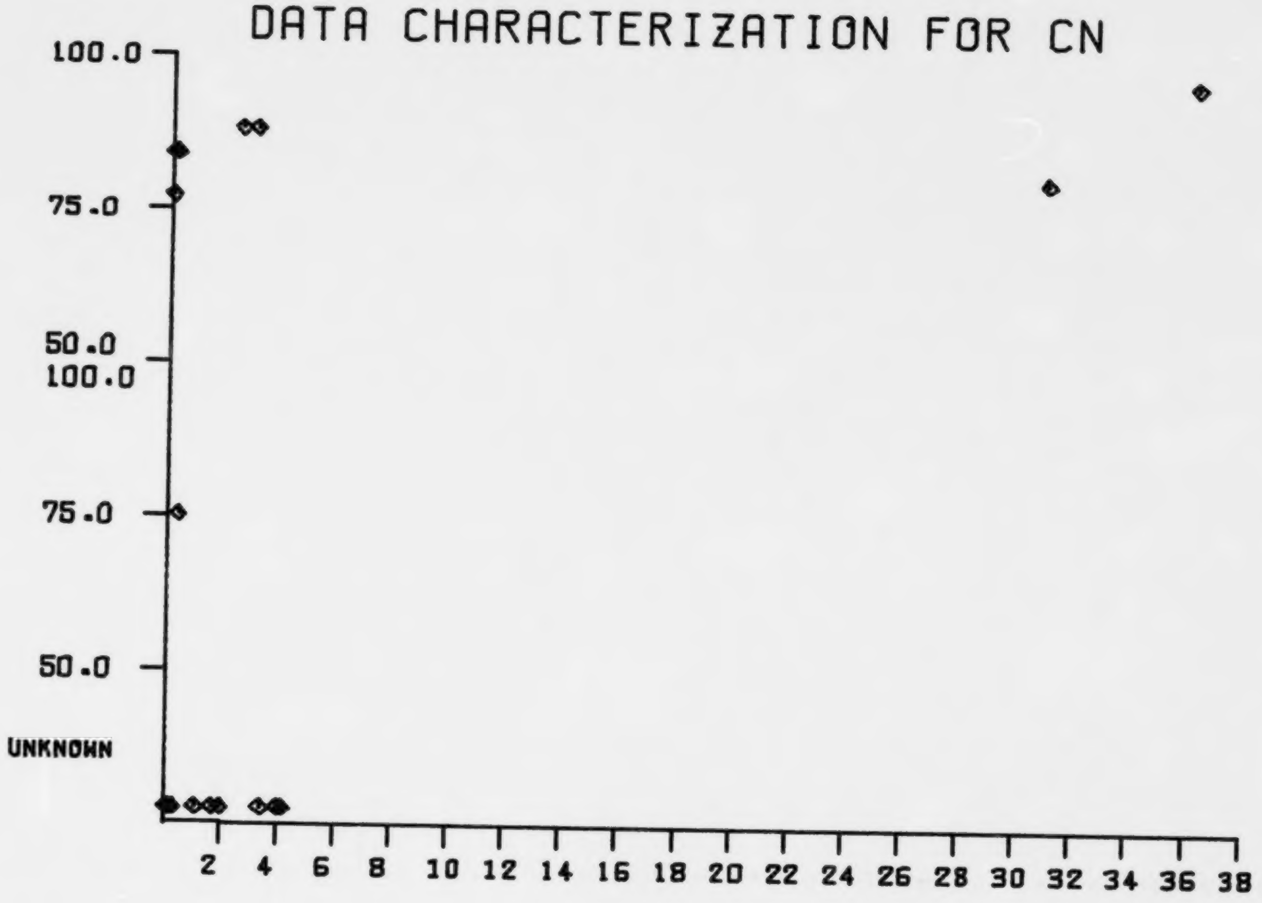
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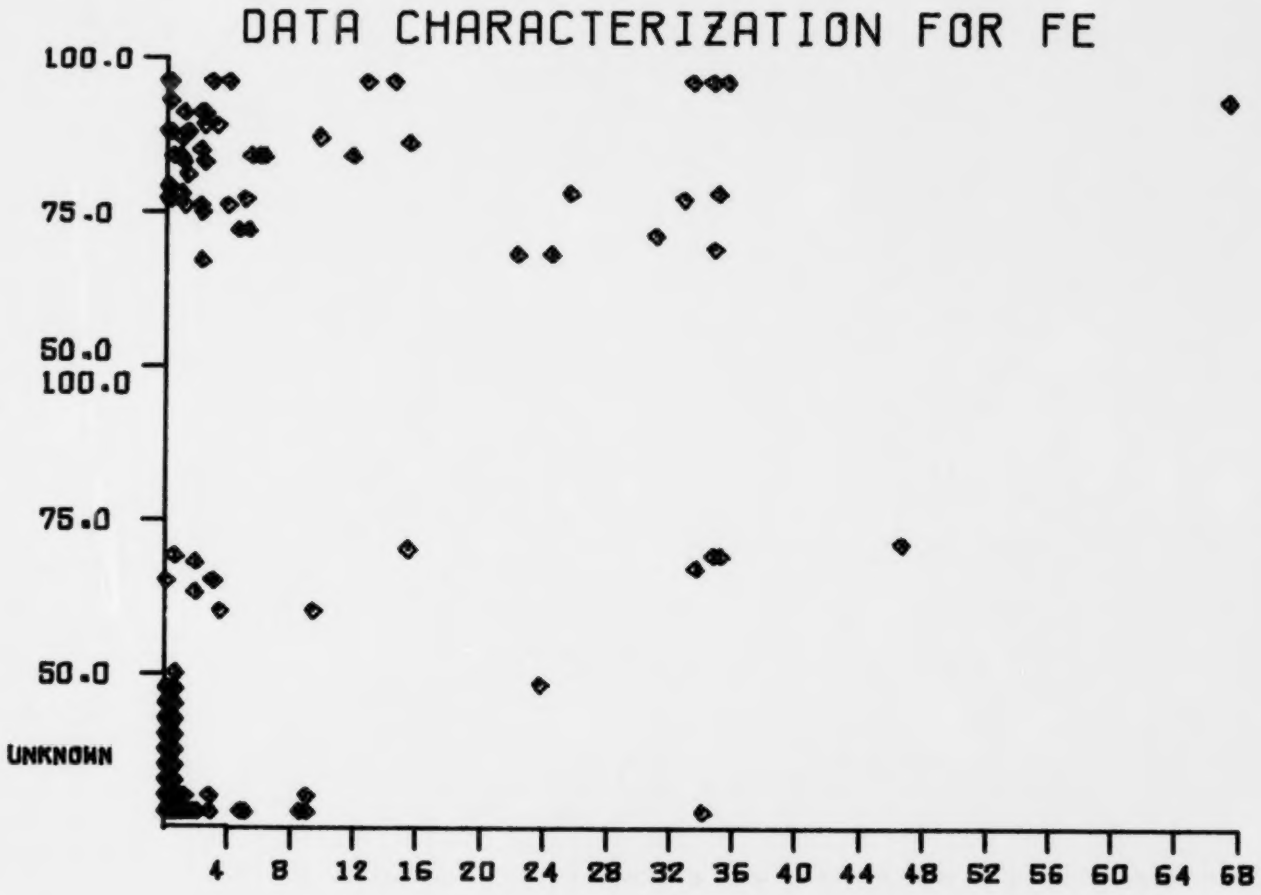
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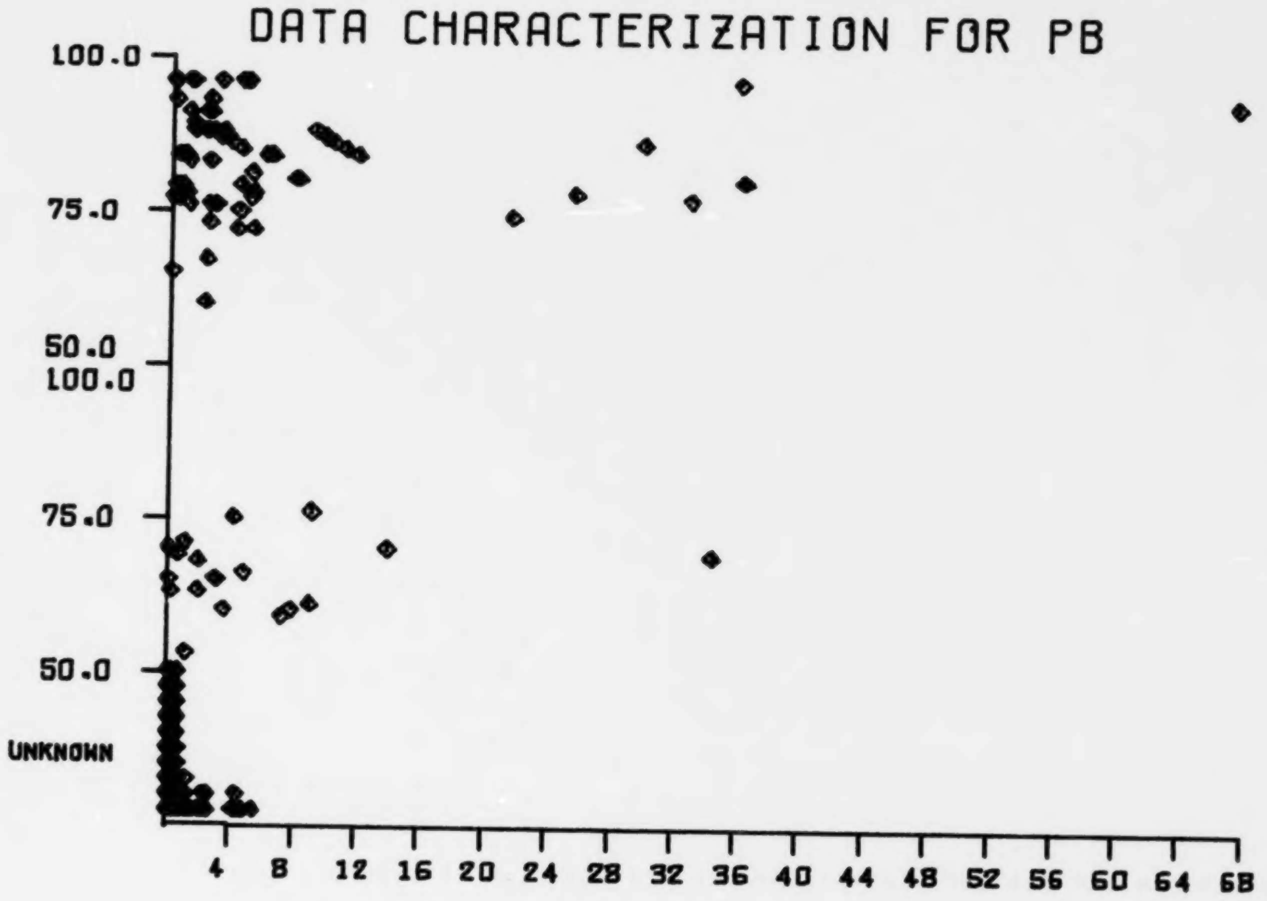
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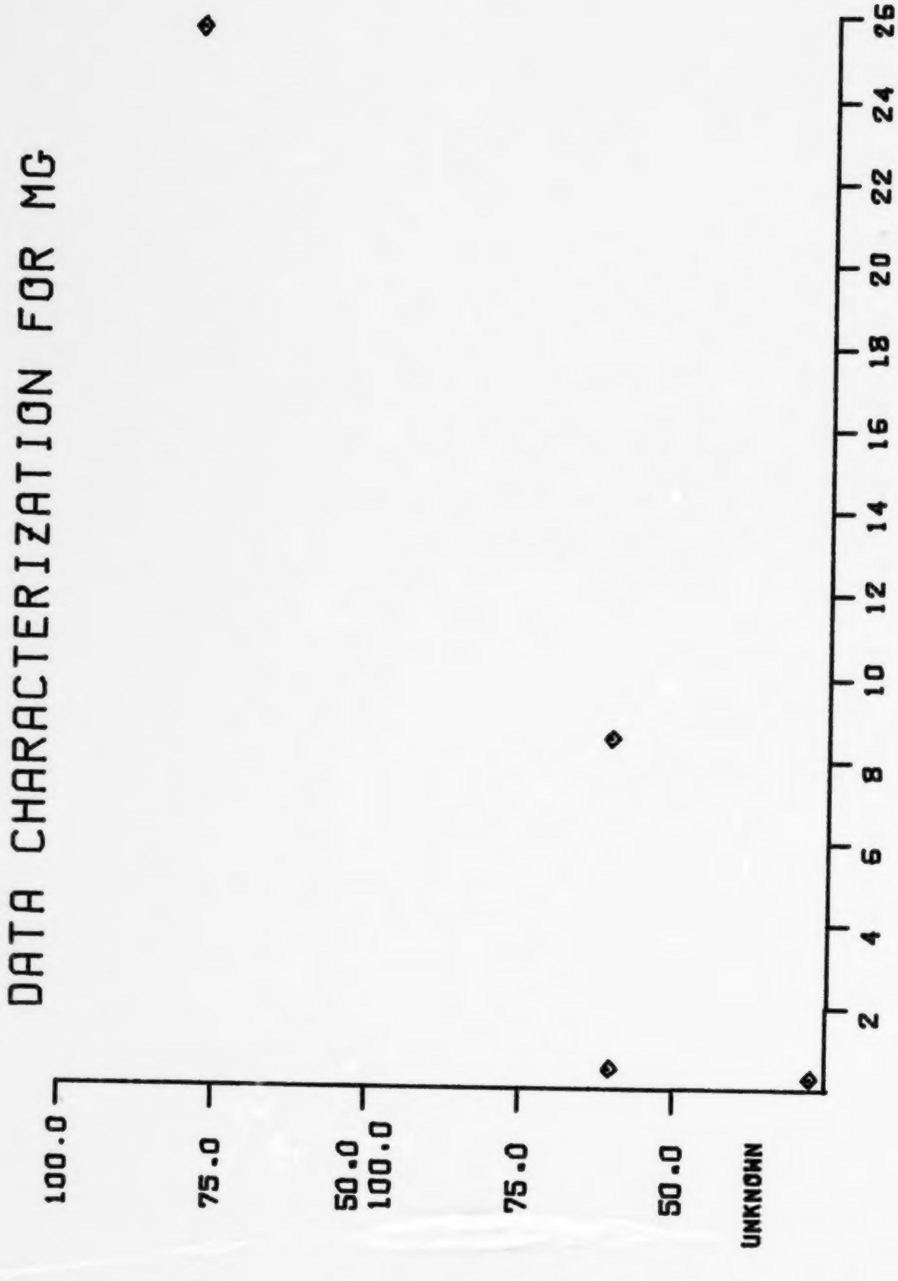
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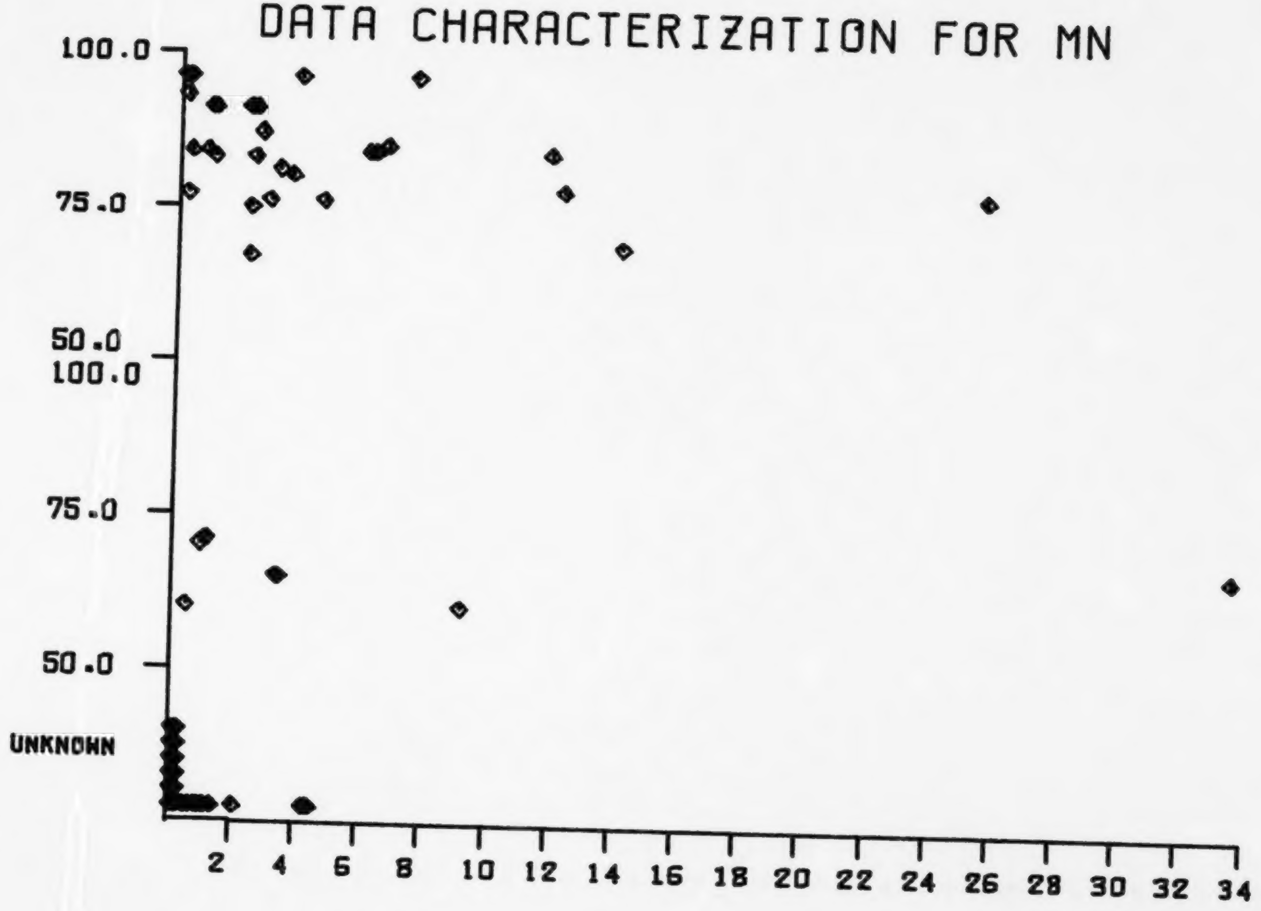
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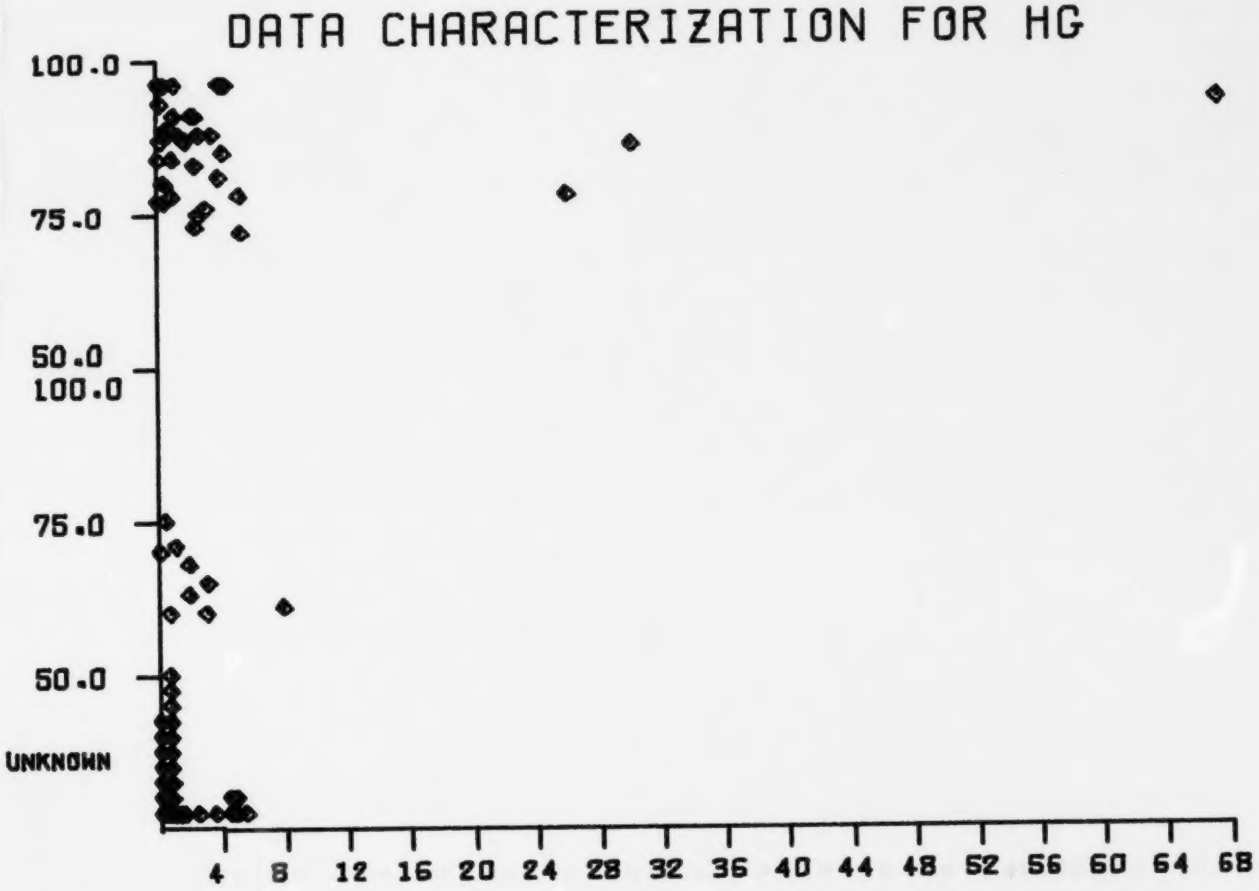
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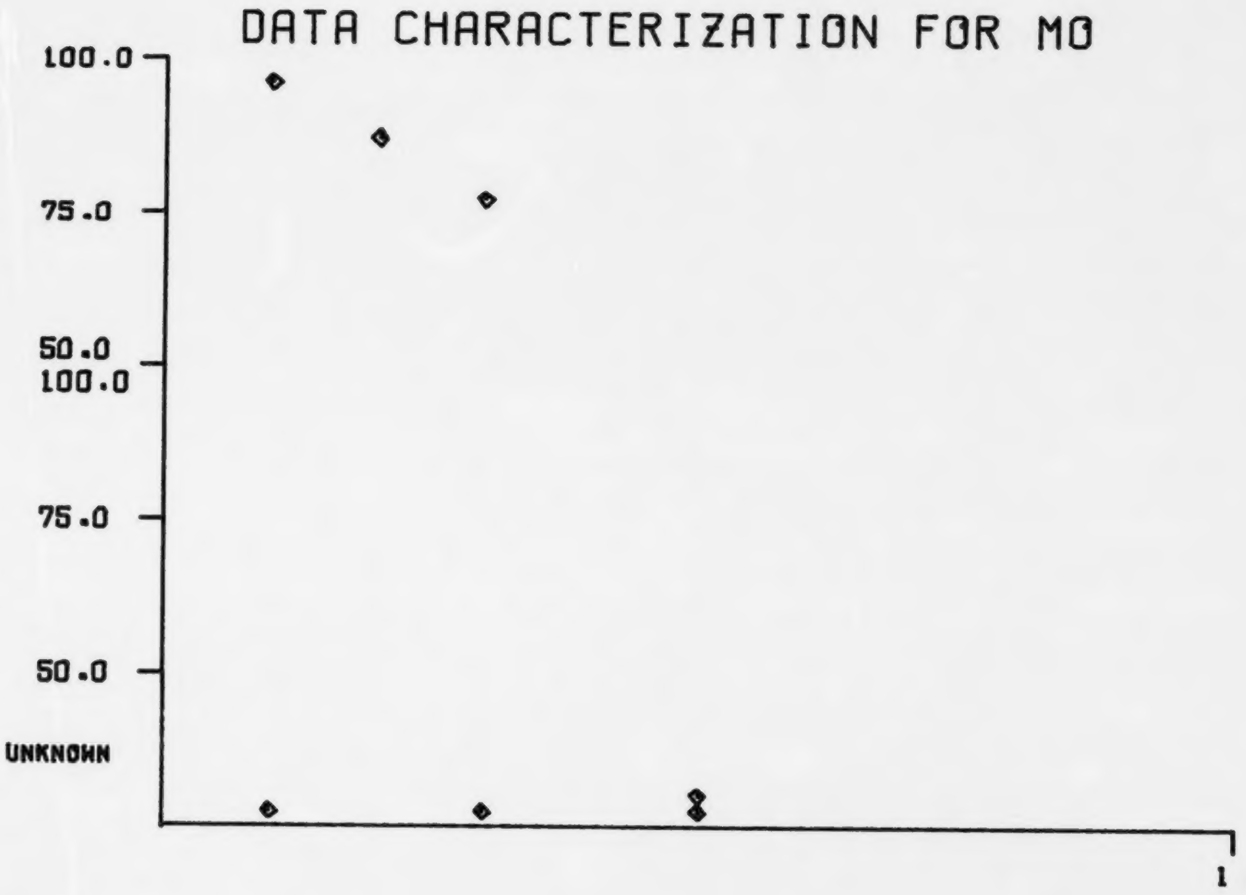
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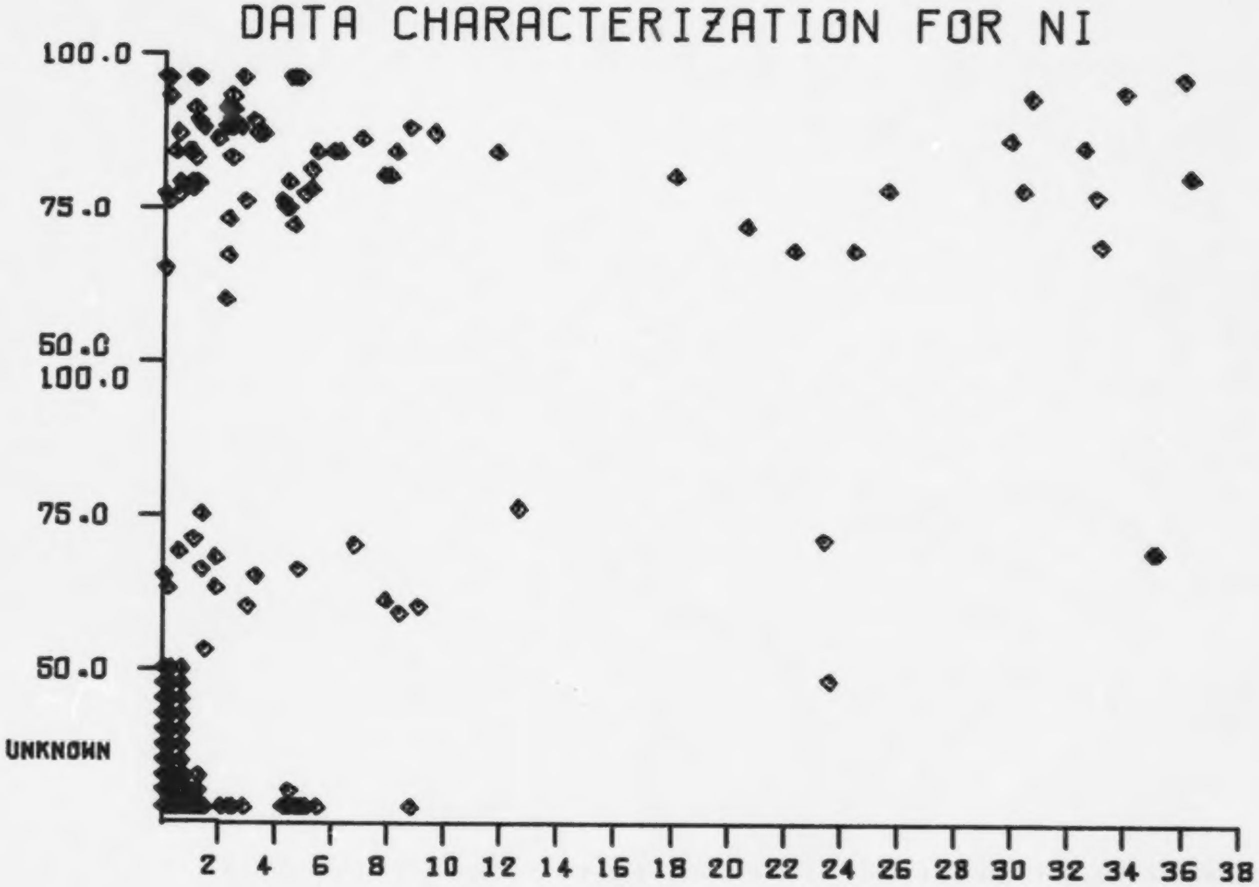
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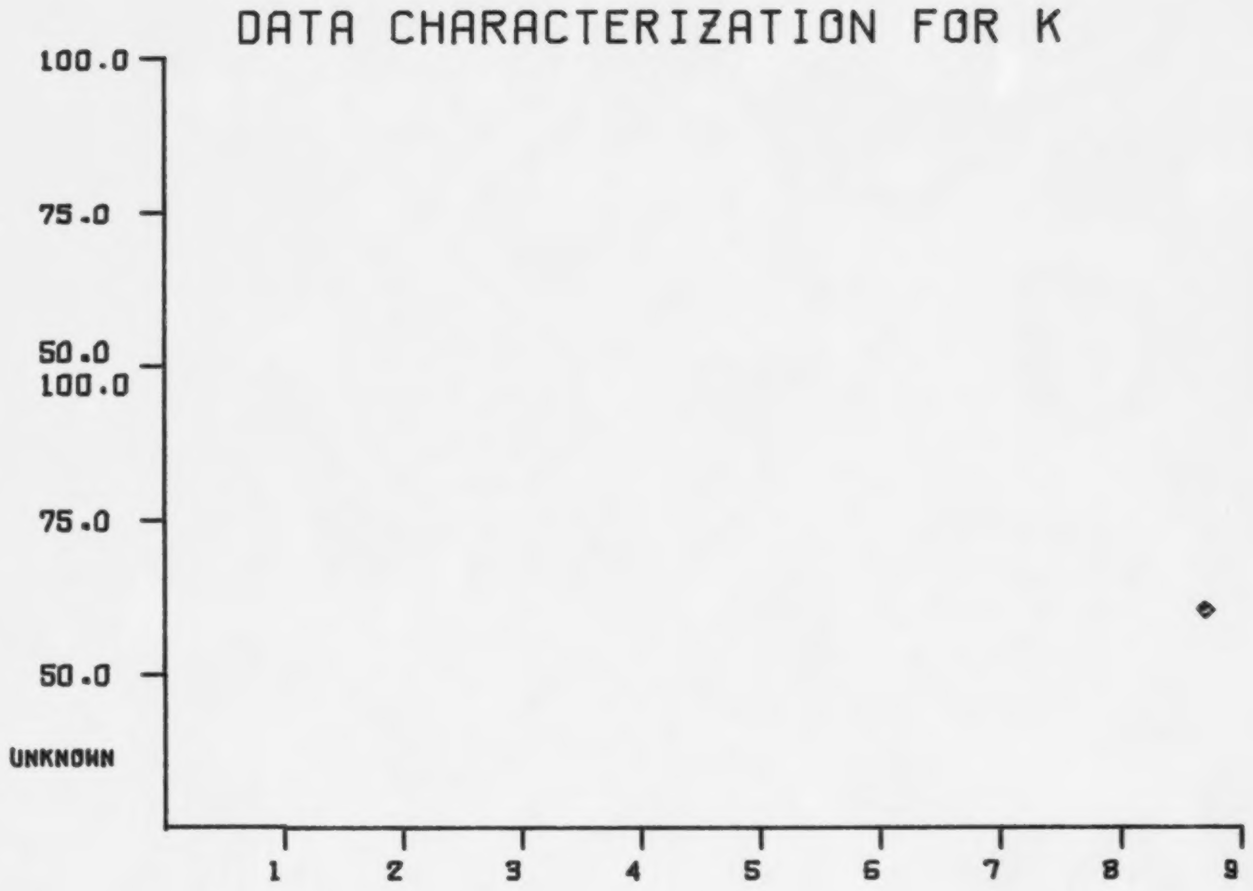
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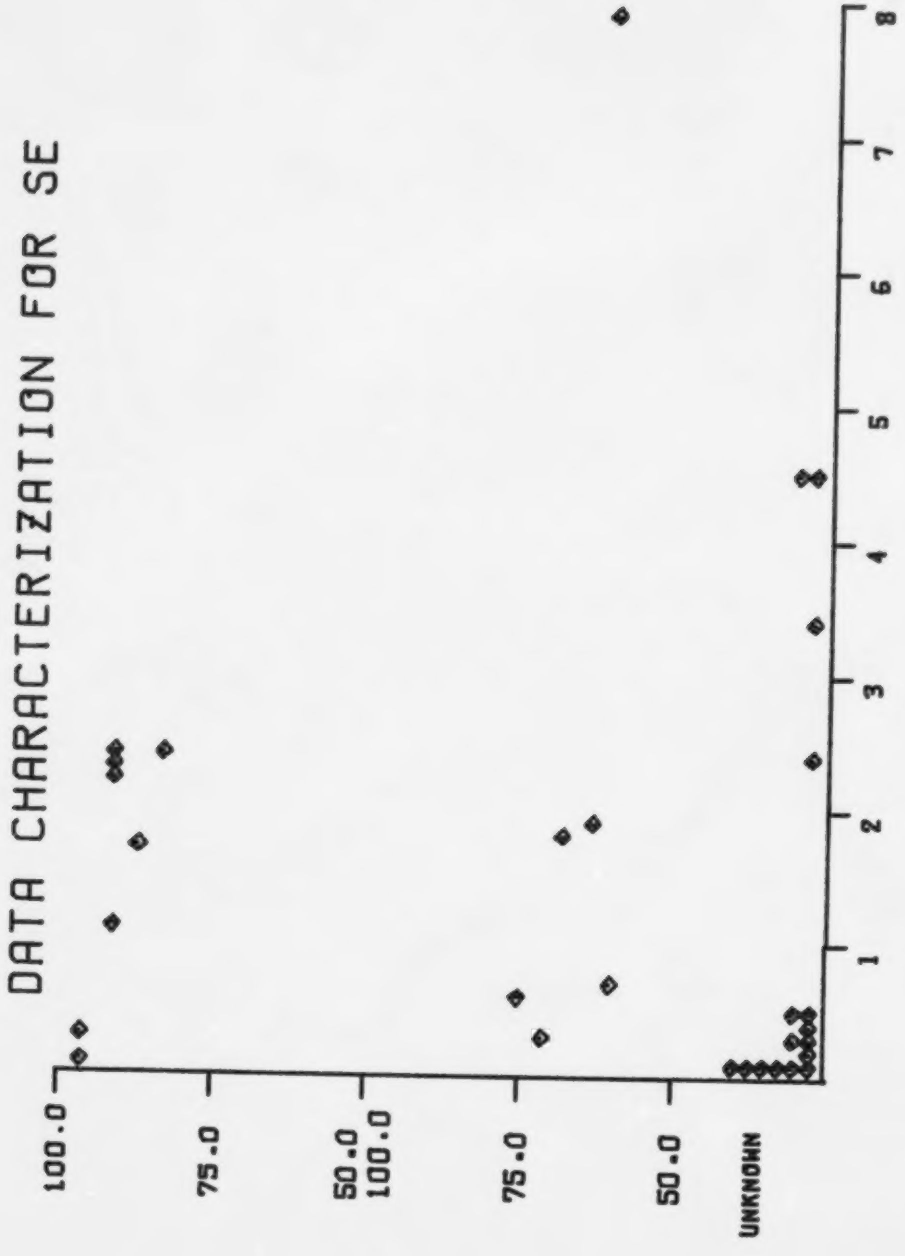
Figure C-22.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7
8

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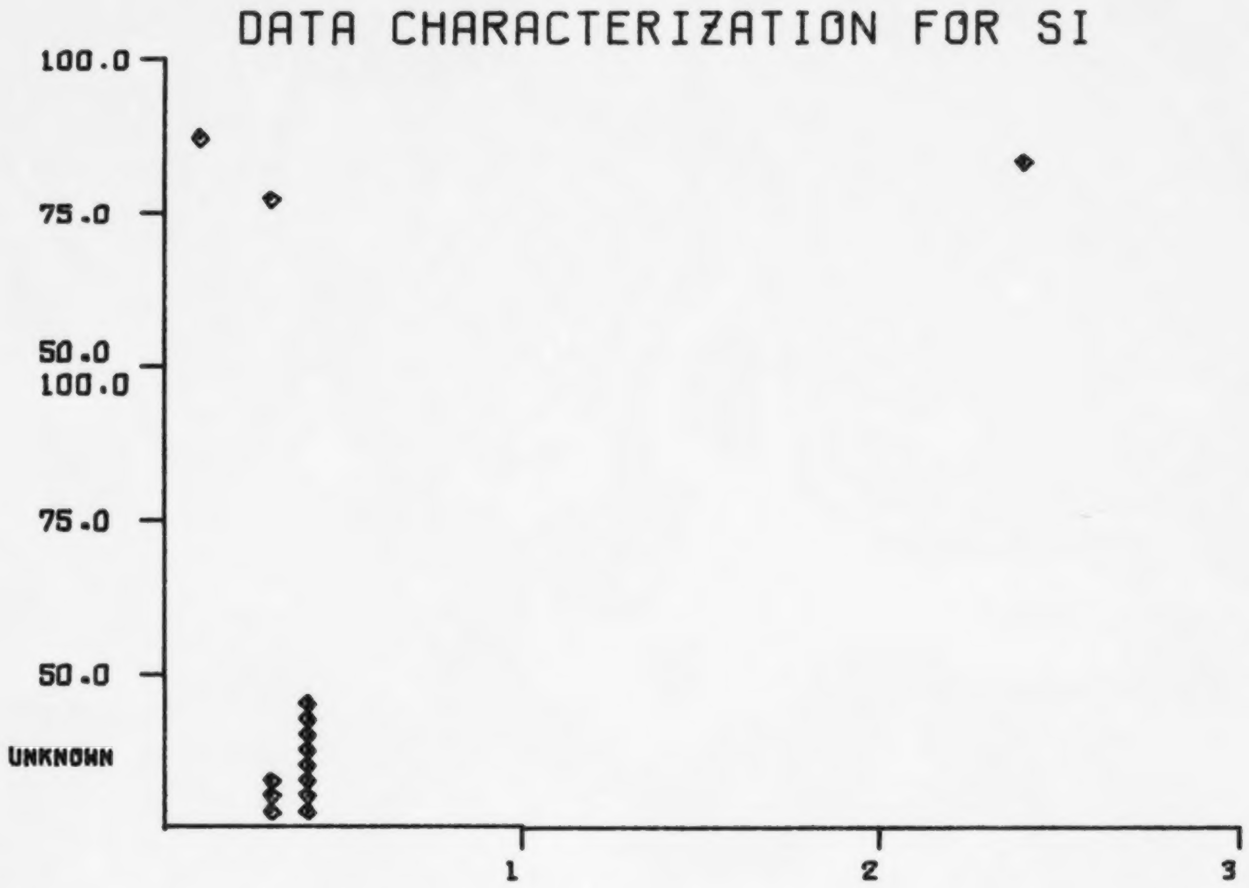
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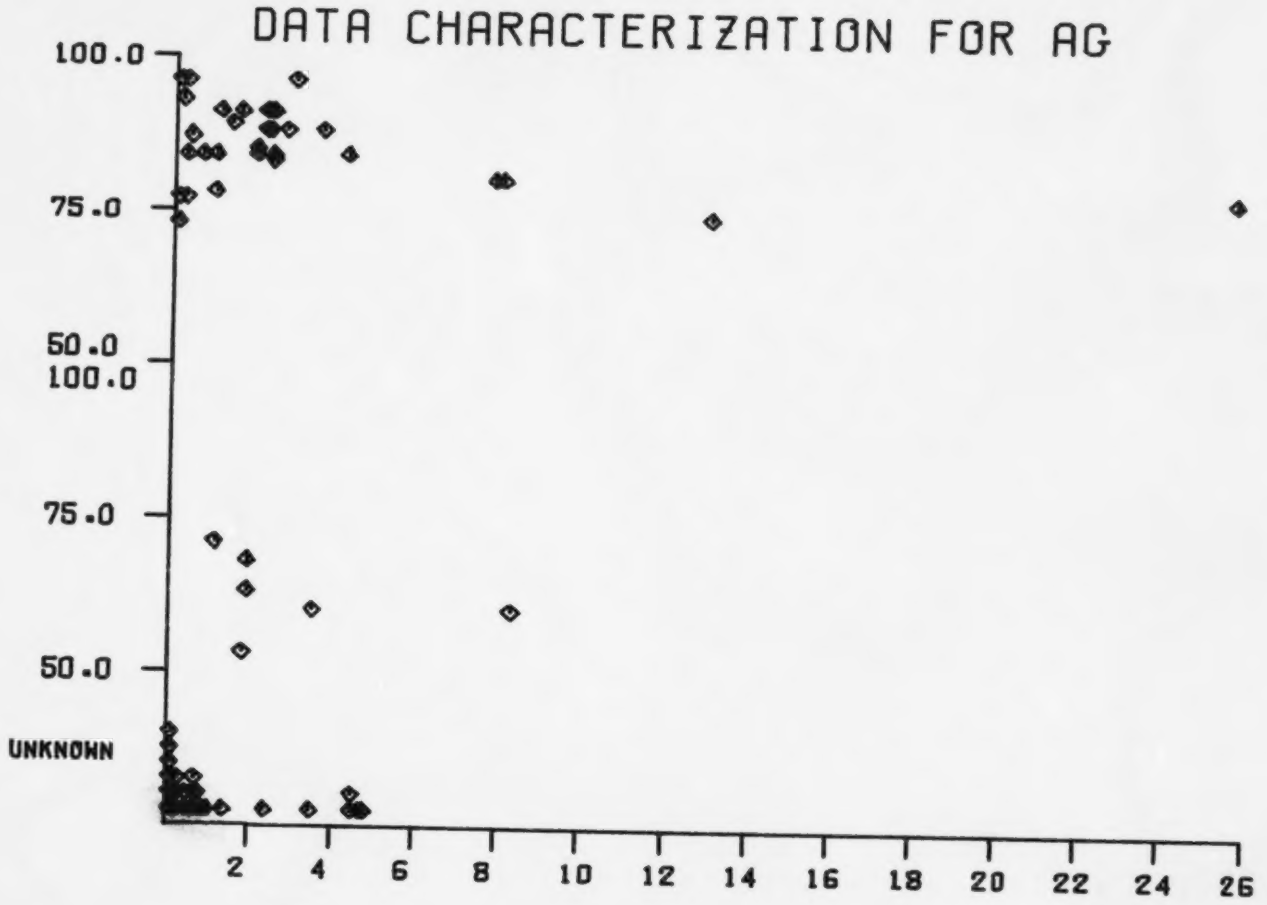
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24
26

Figure C-25.

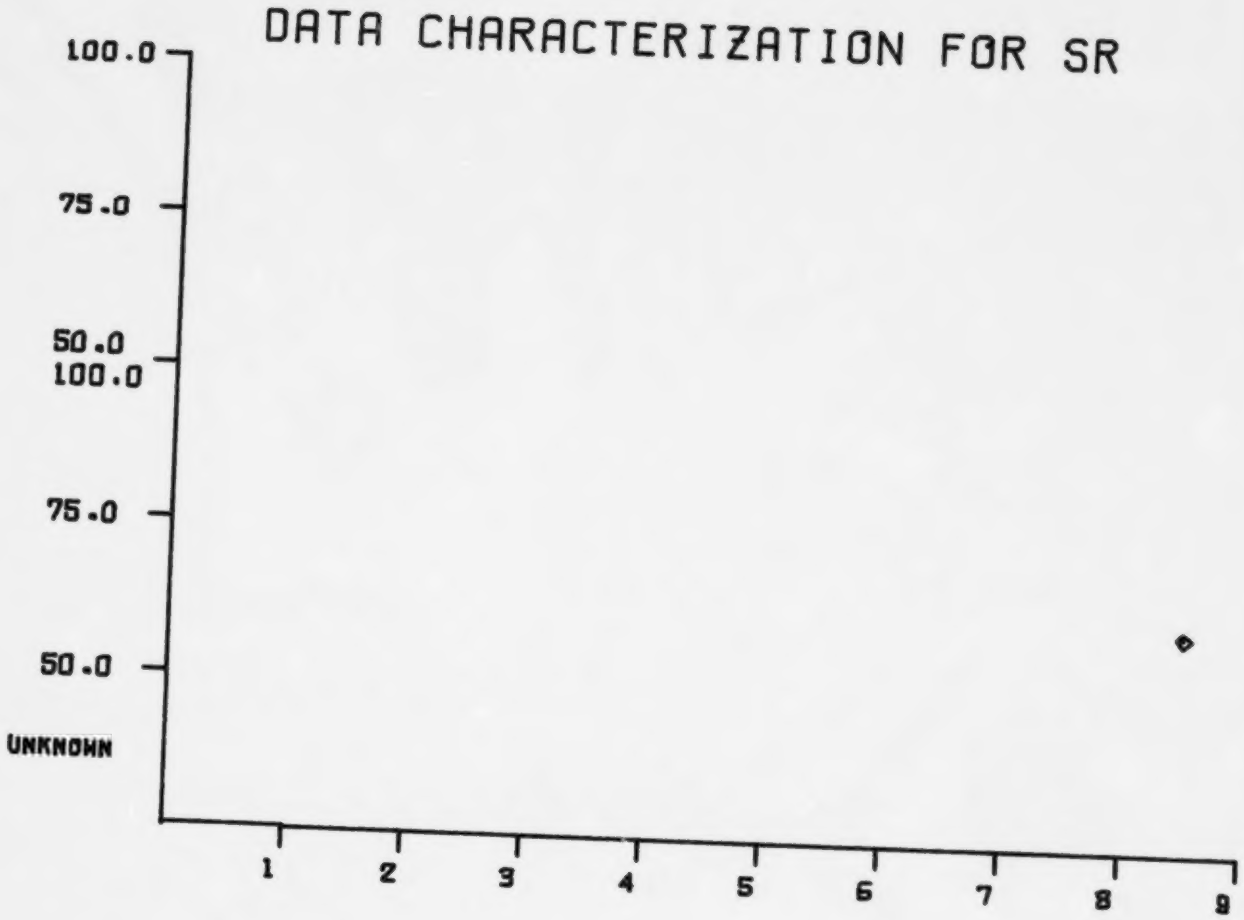
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Figure C-26.

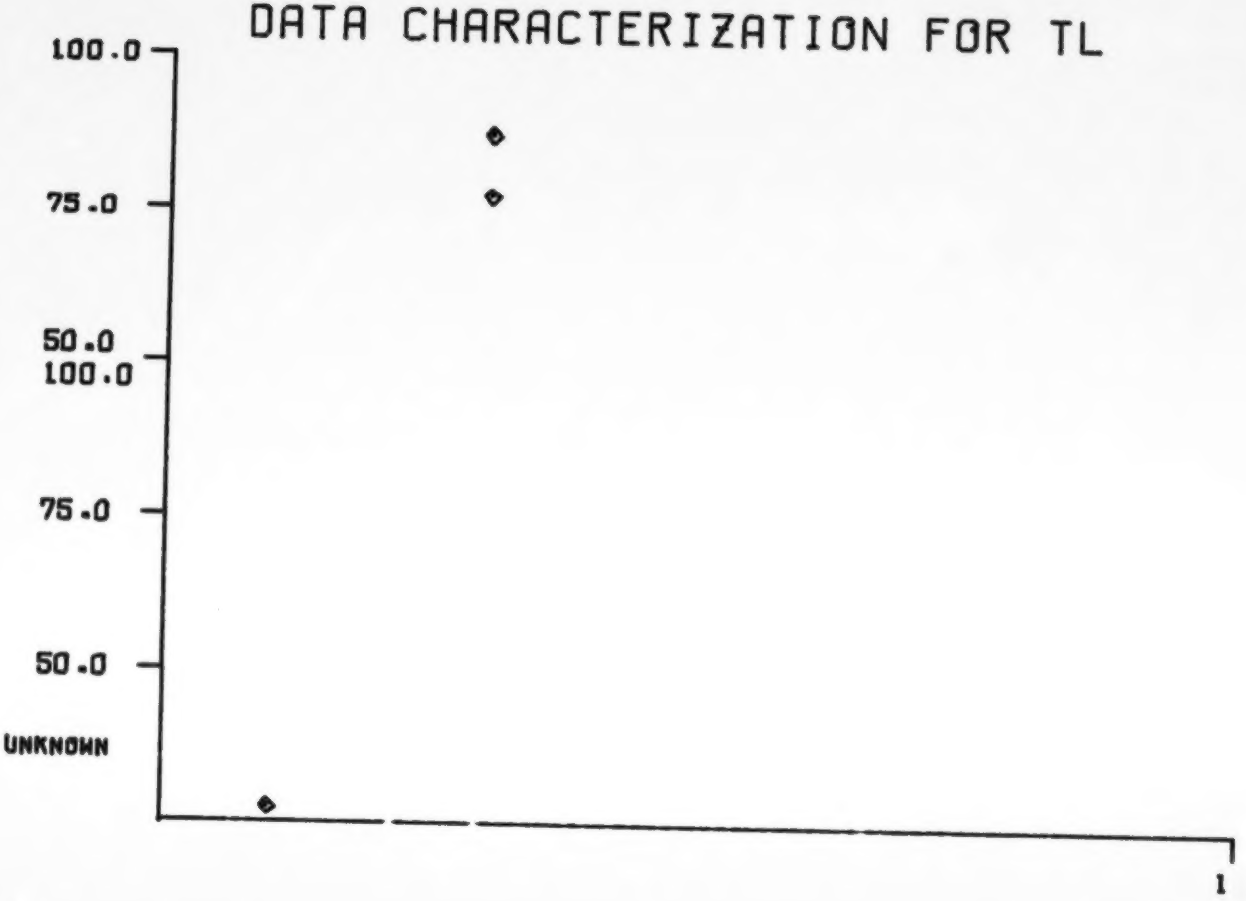
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Figure C-27.

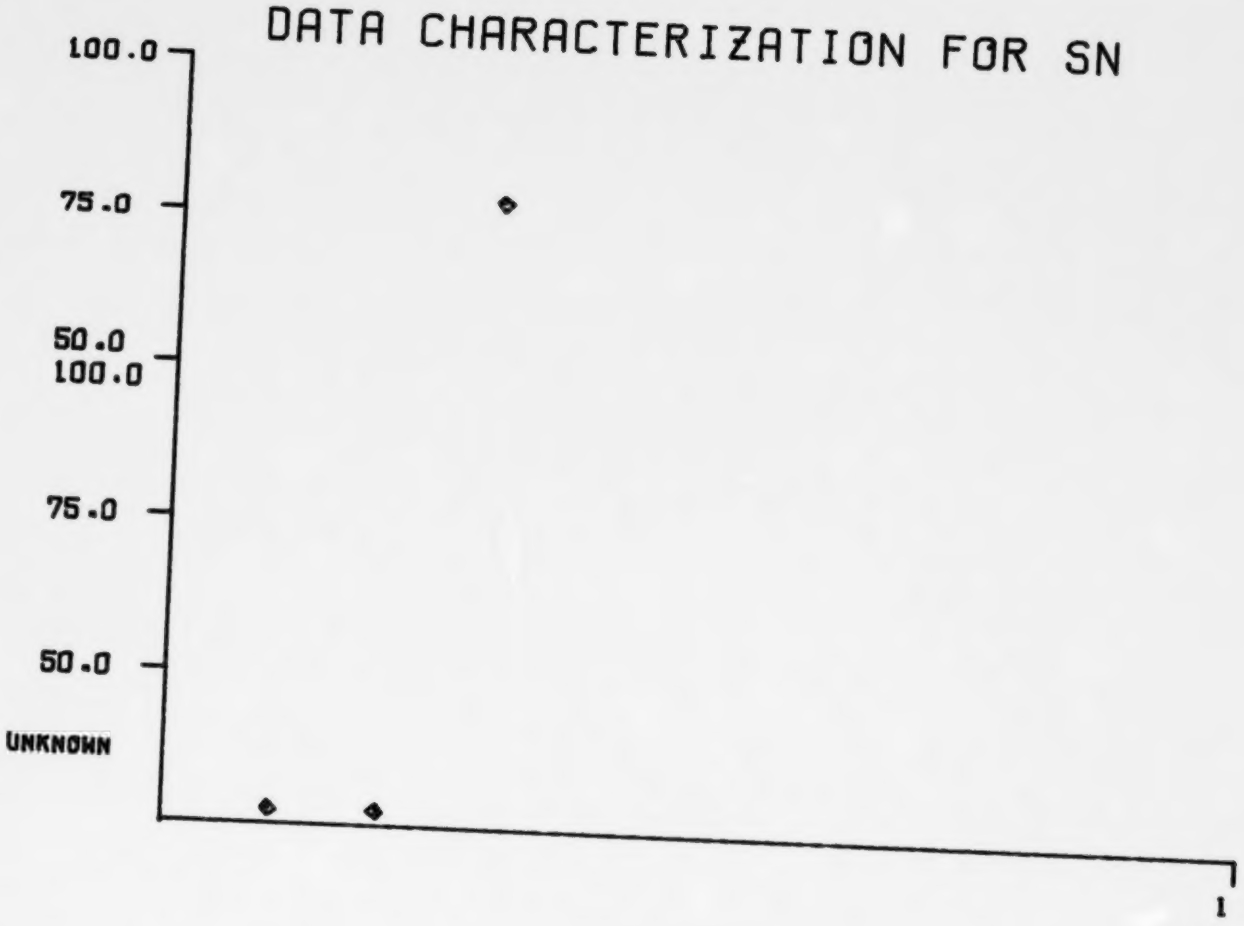
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Figure C-28.

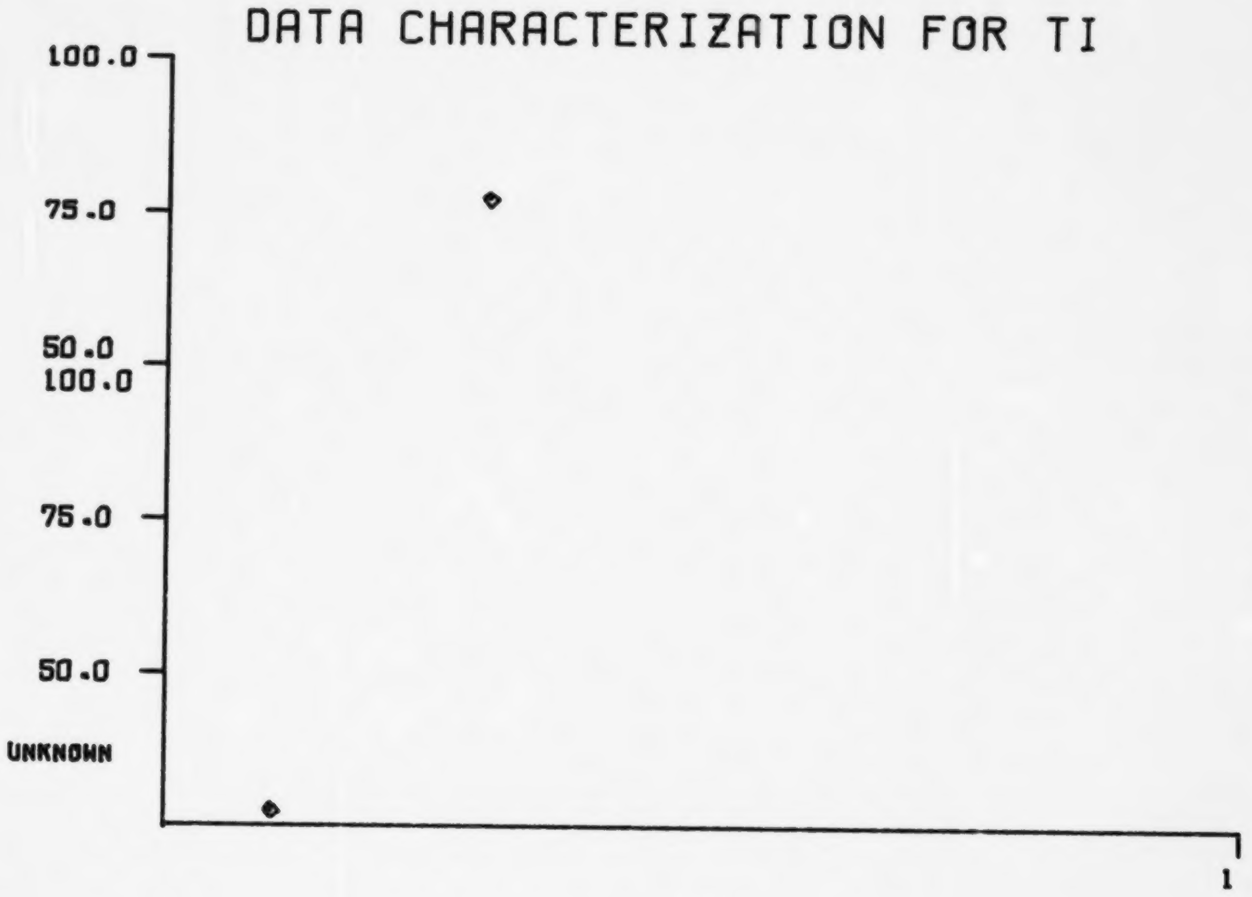
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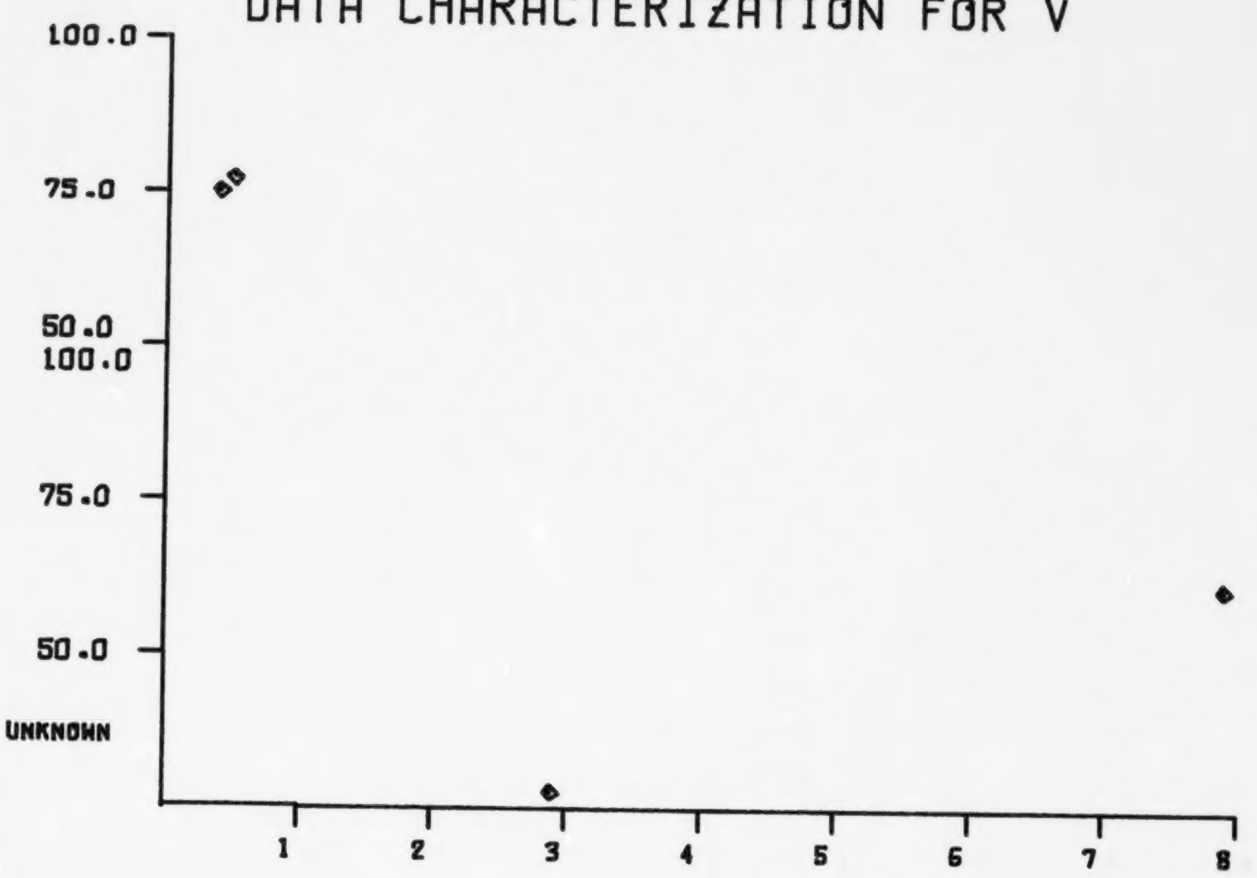
Figure C-29.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5
6
7
8

Figure C-30.

APPENDIX D

DATA CHARACTERIZATION PLOTS FOR

1. MARCH/APRIL (D1 to D29)

2. SEPTEMBER/OCTOBER (D30 to D59)

Data are presented as a number of observations in tens (x axis) versus the LQI scores on the y axis. The upper range is for laboratories which failed zero or only 1 critical category. The middle range contains those laboratories failing more than 1 critical category. The bottom range contains those laboratories for which no LQI was obtained.

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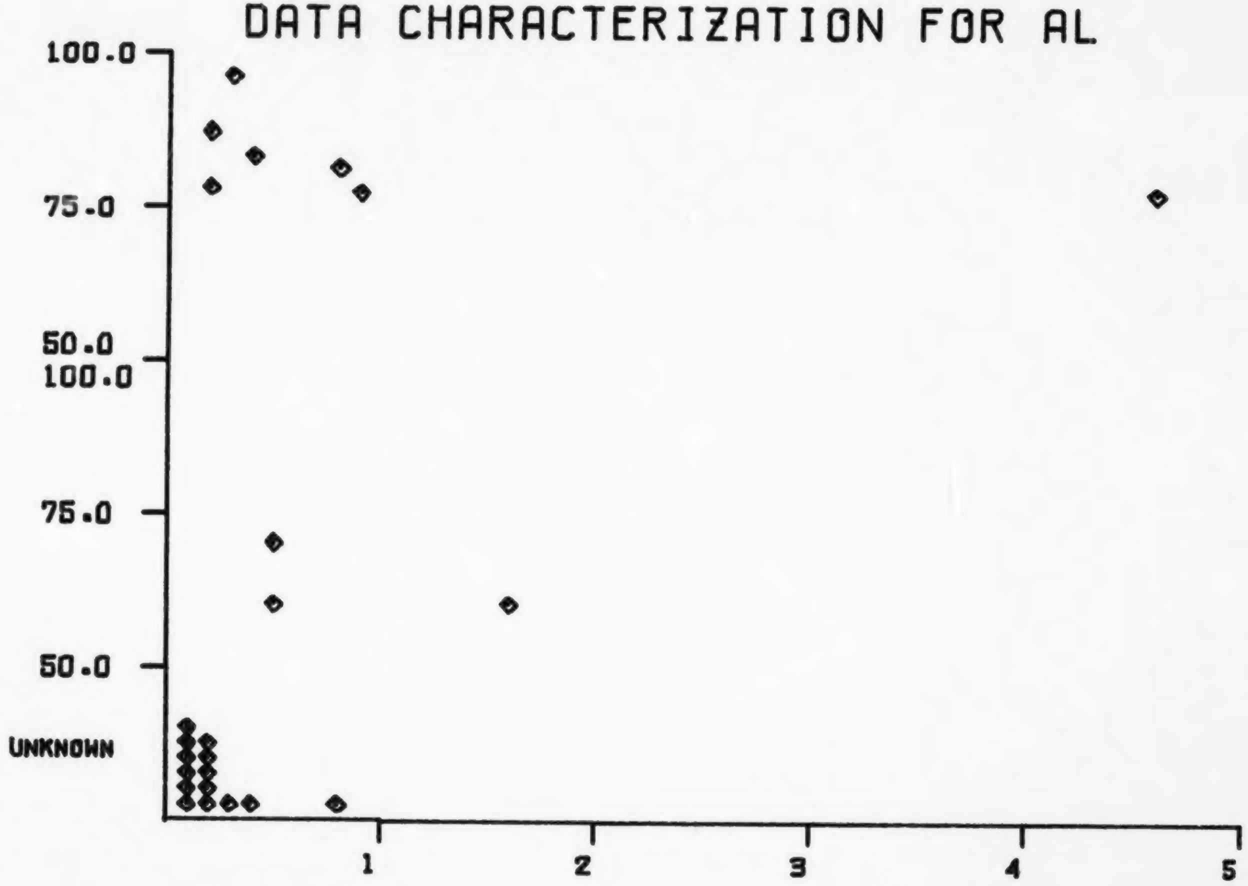
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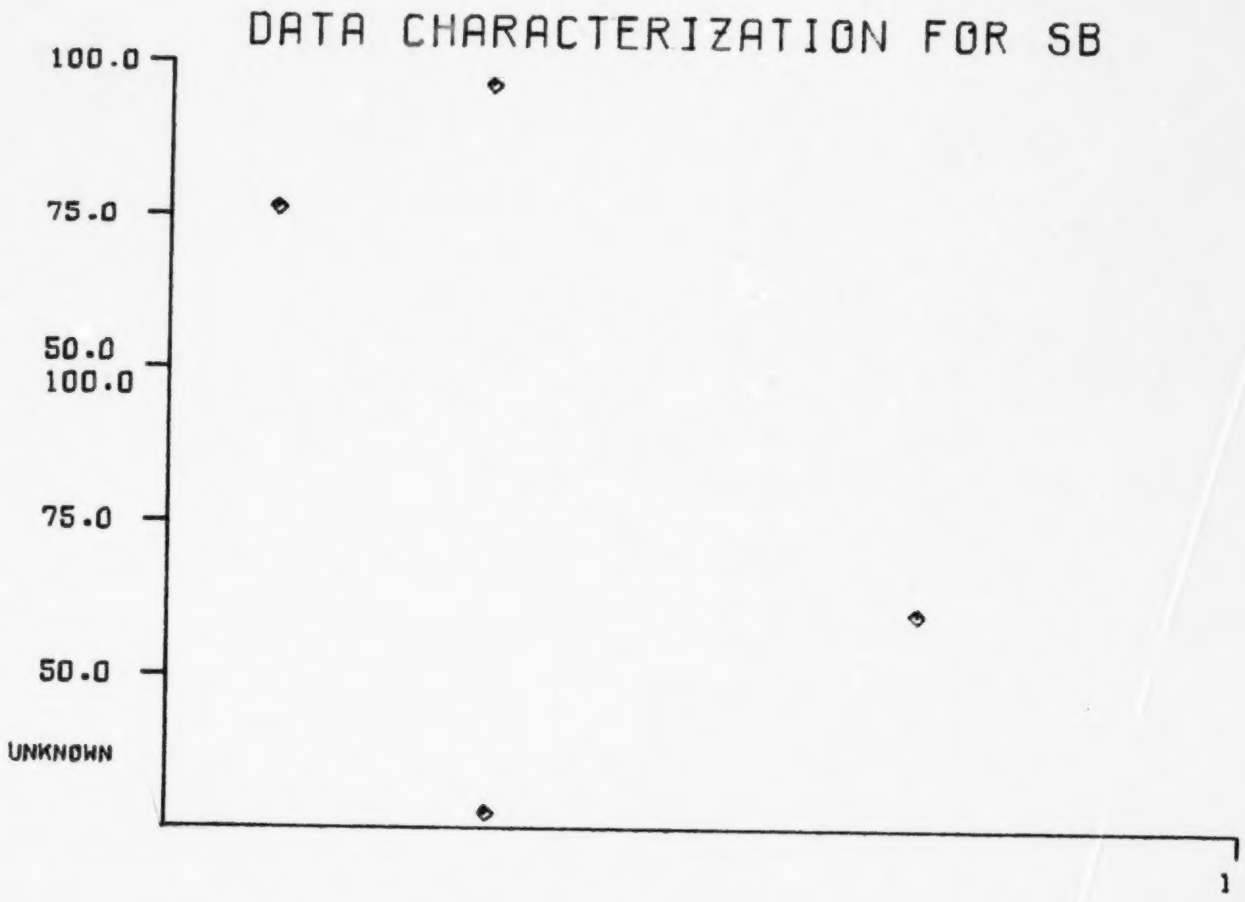
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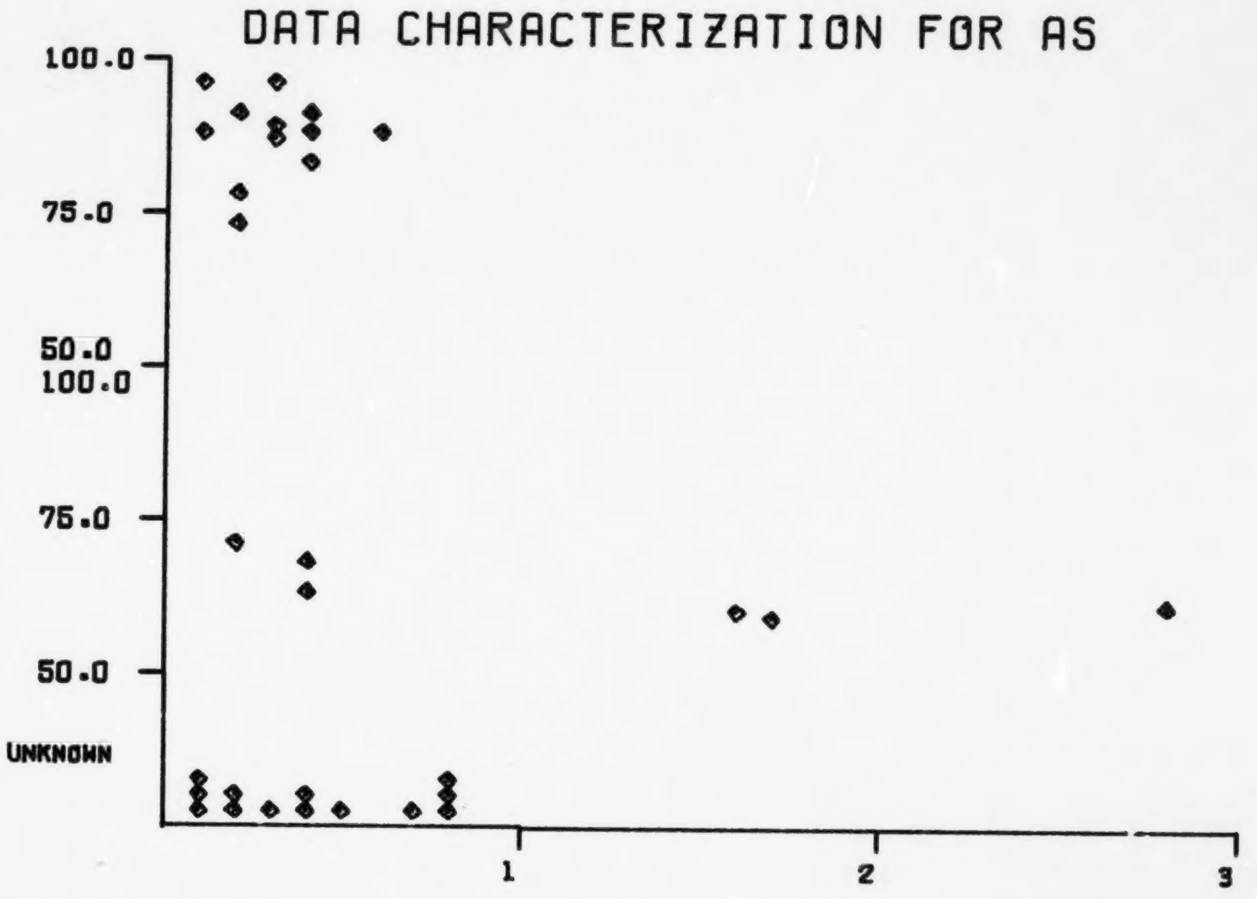
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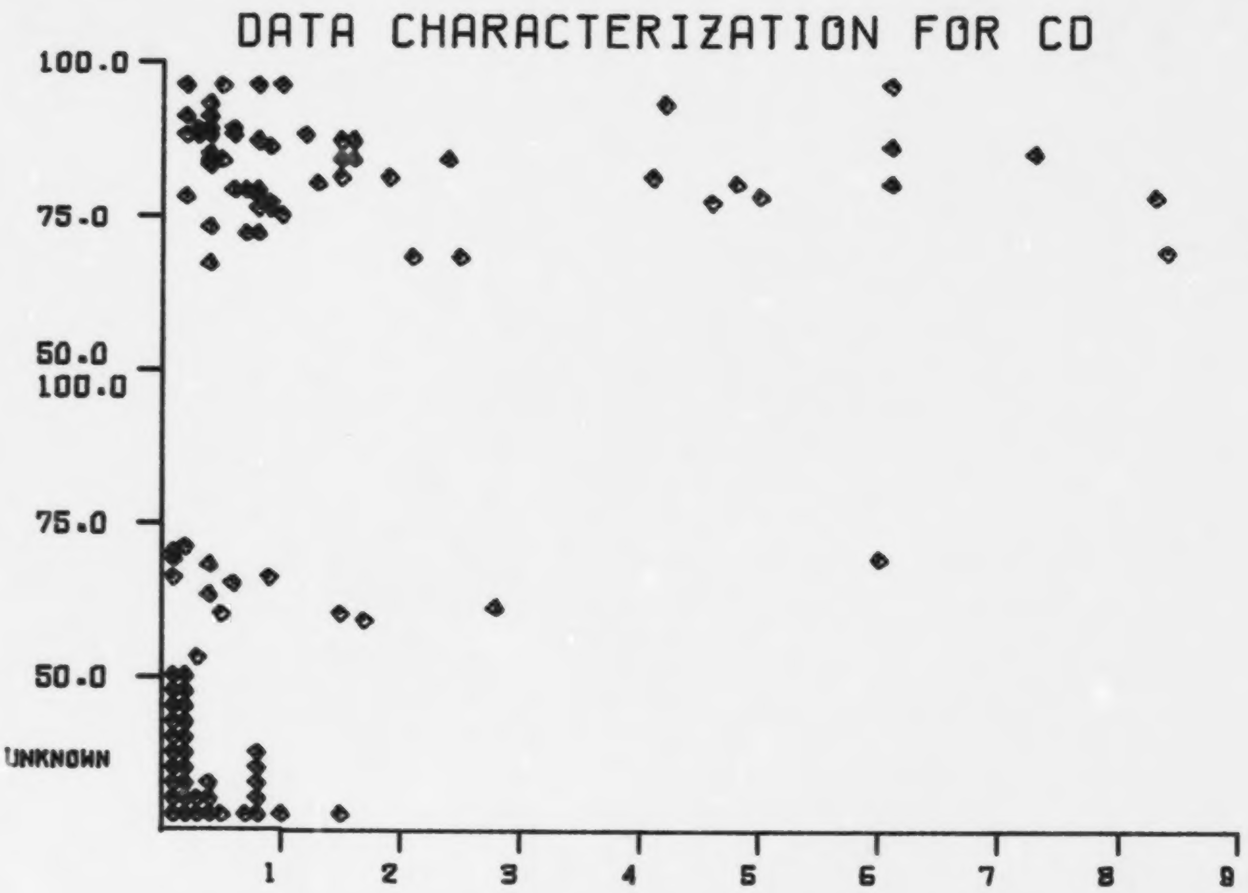
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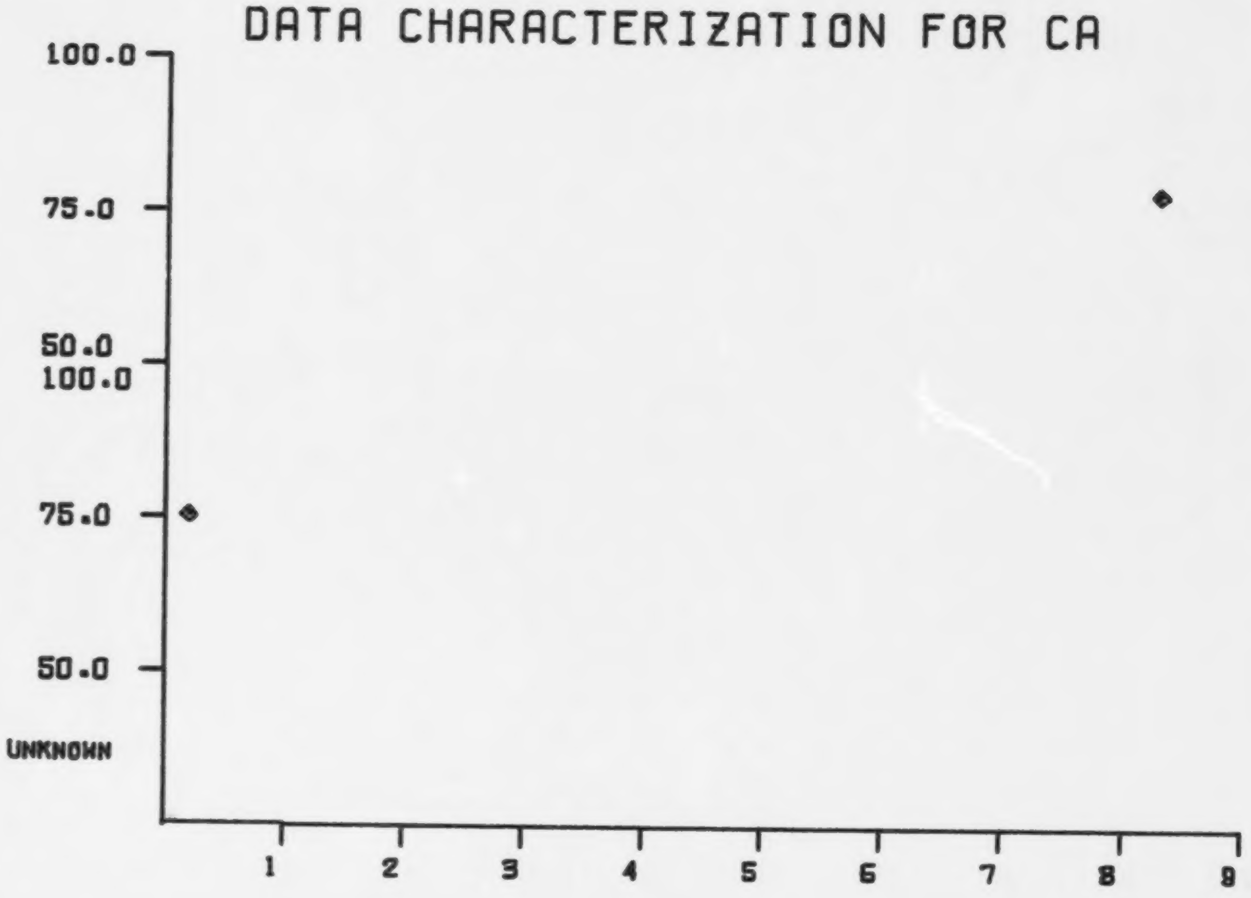
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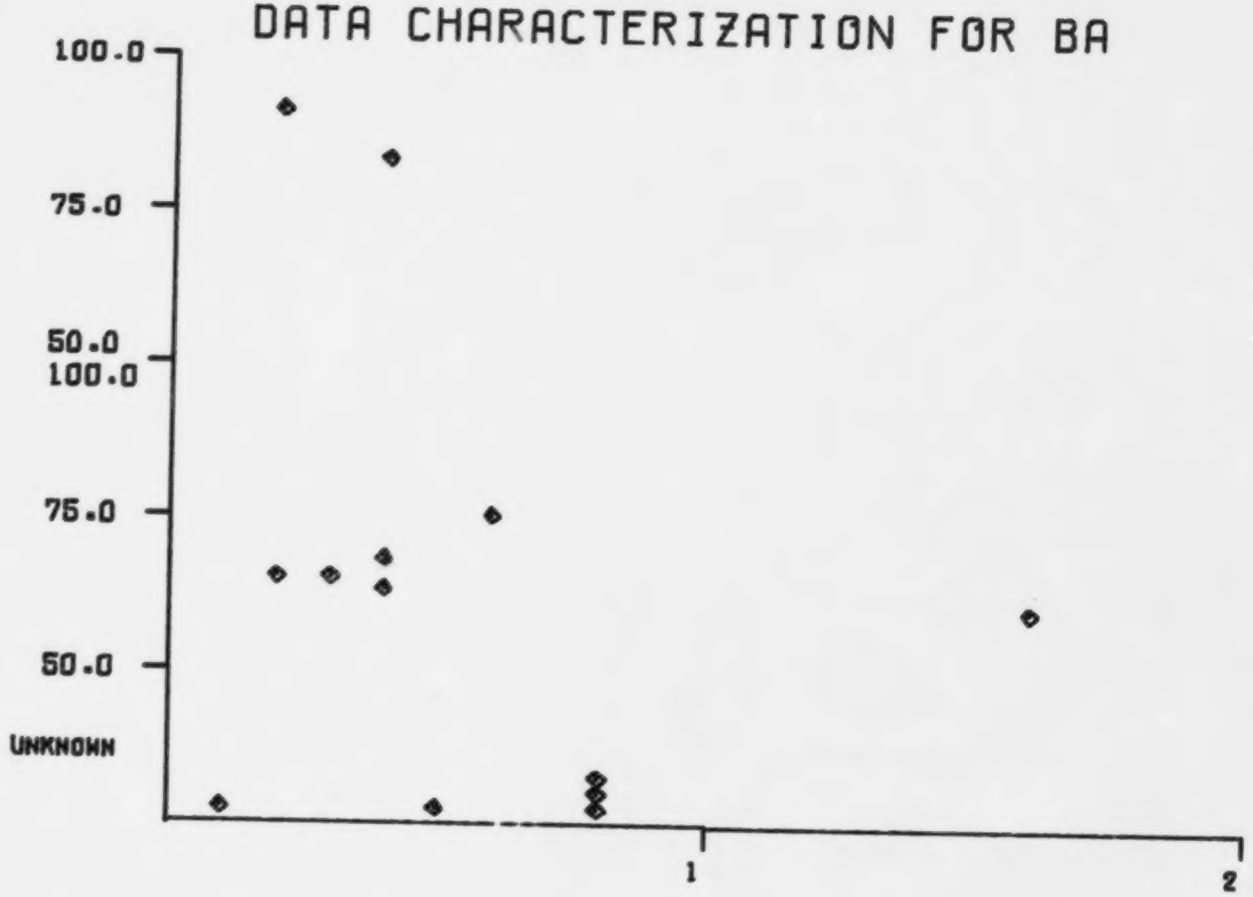
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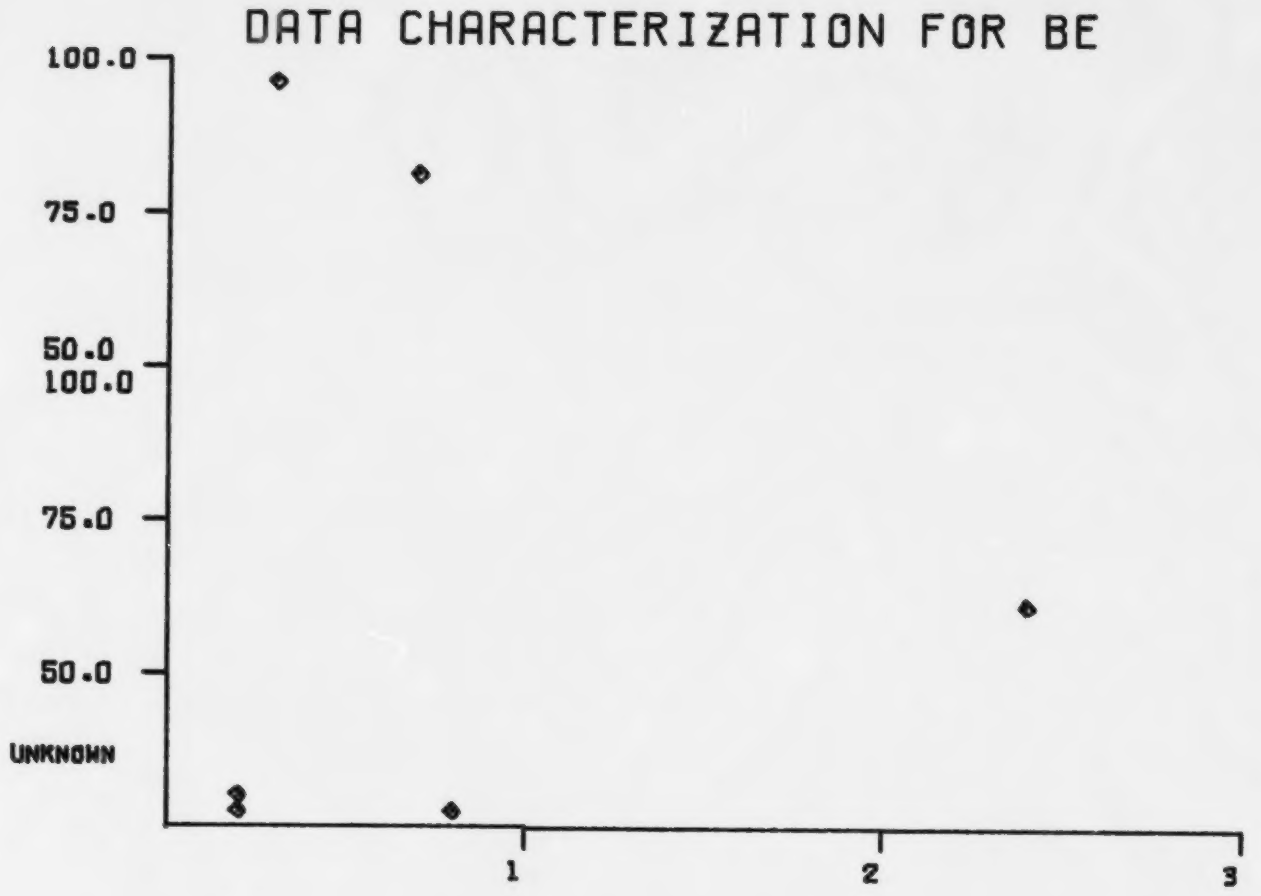
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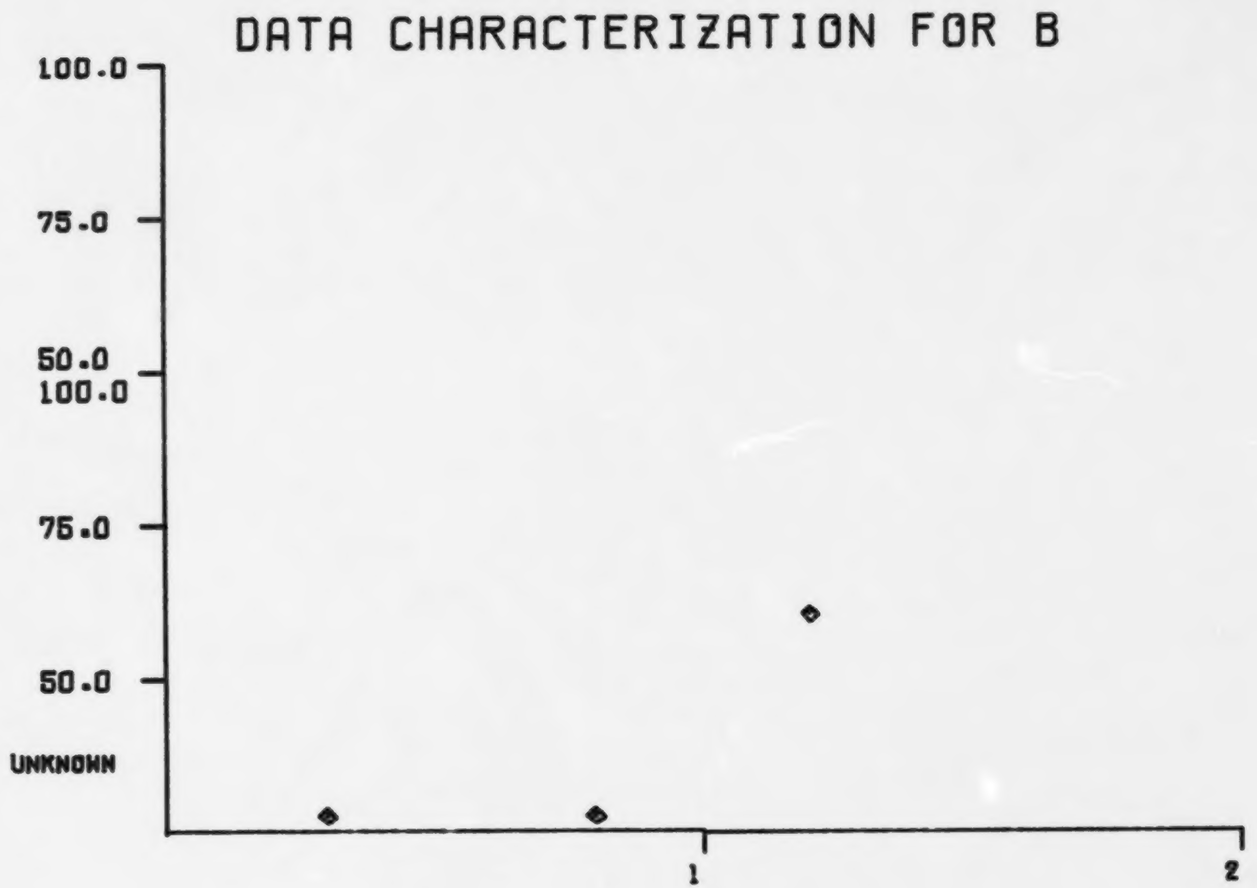
Figure D-7.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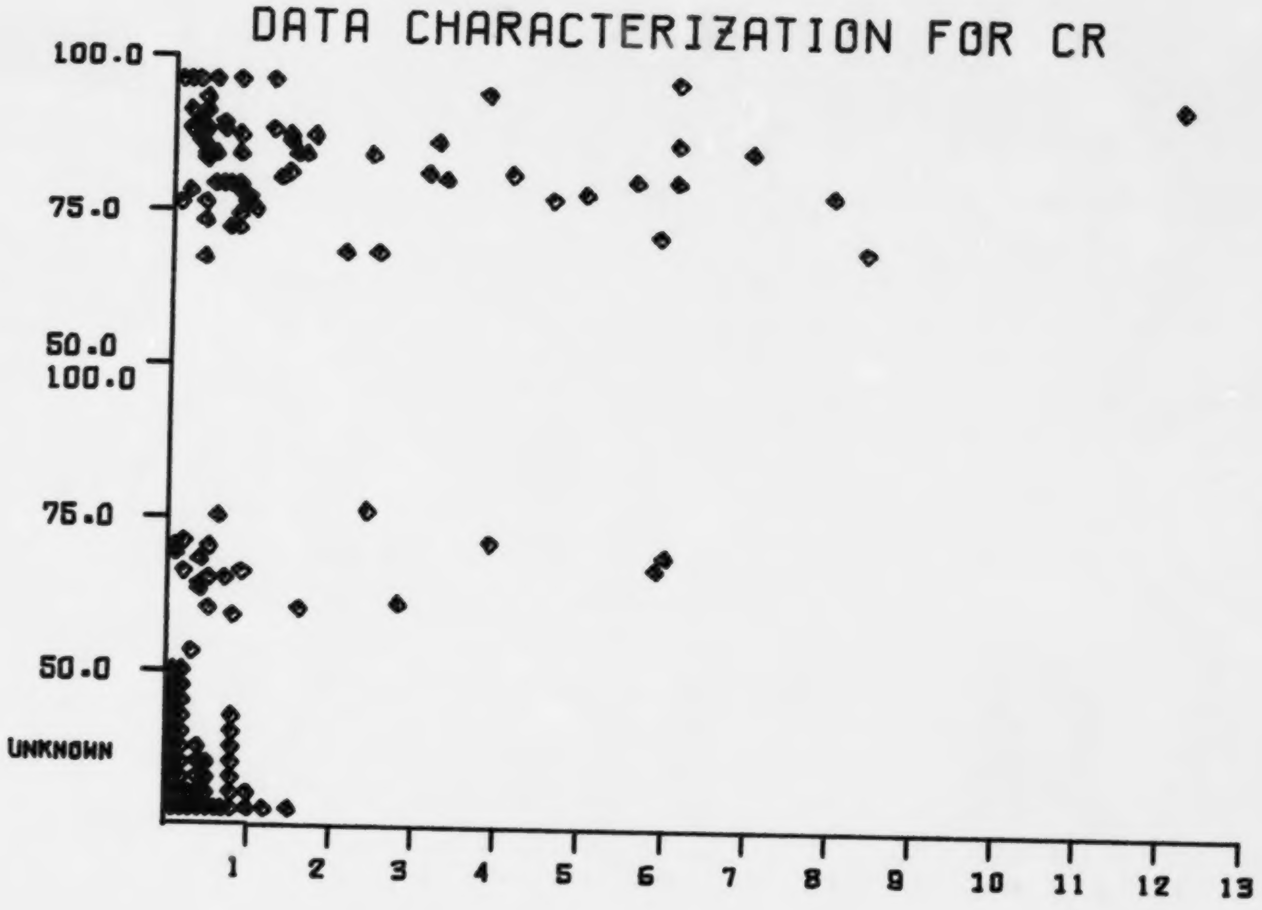
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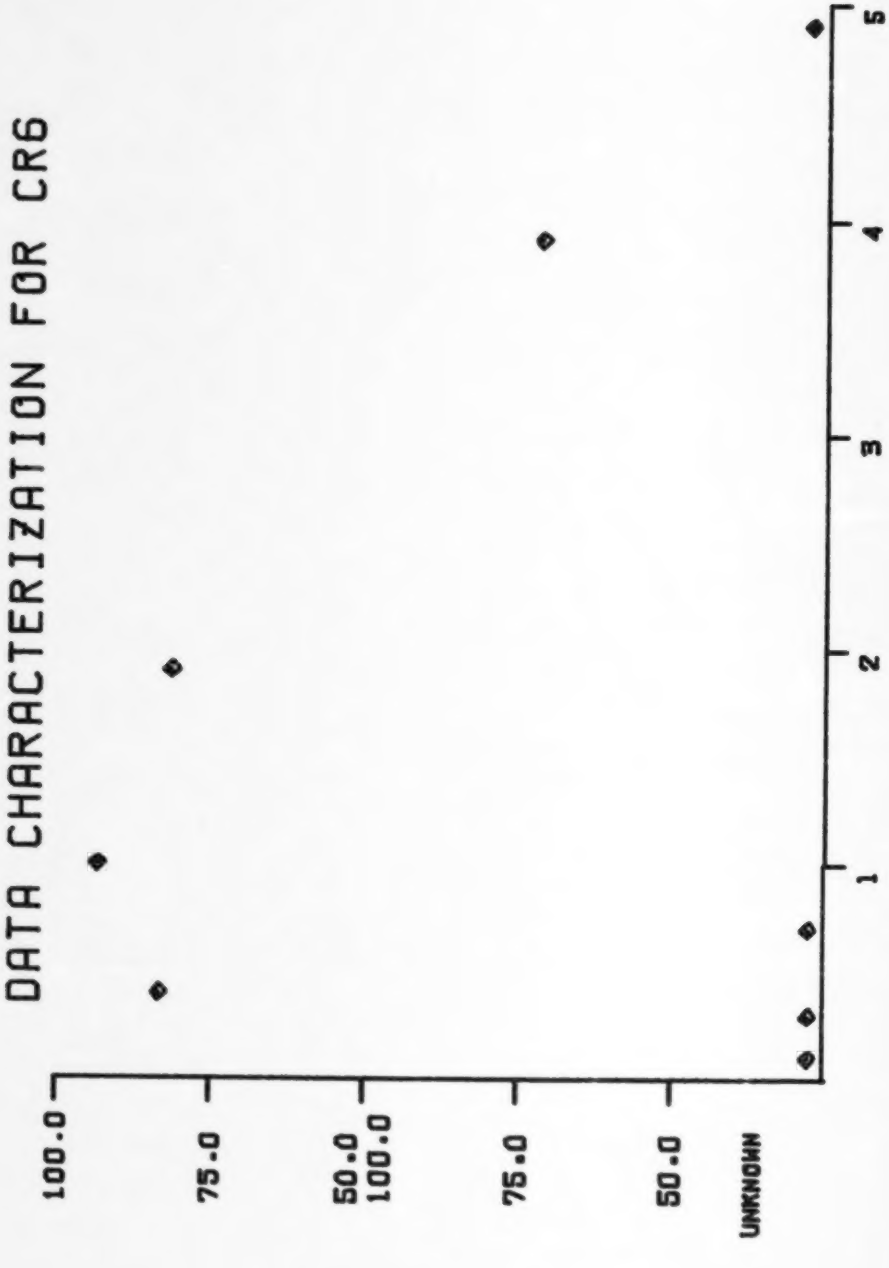
13

Figure D-9.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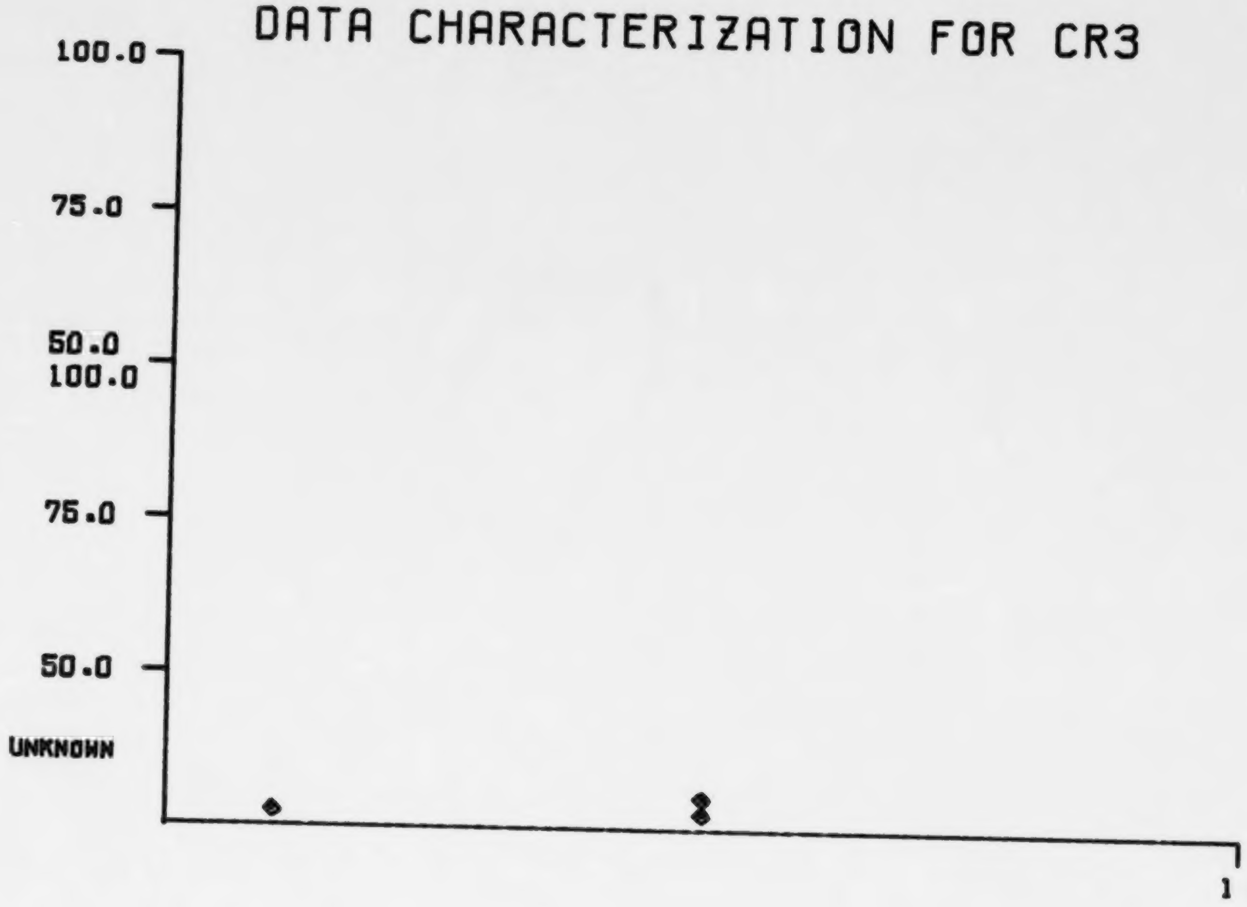
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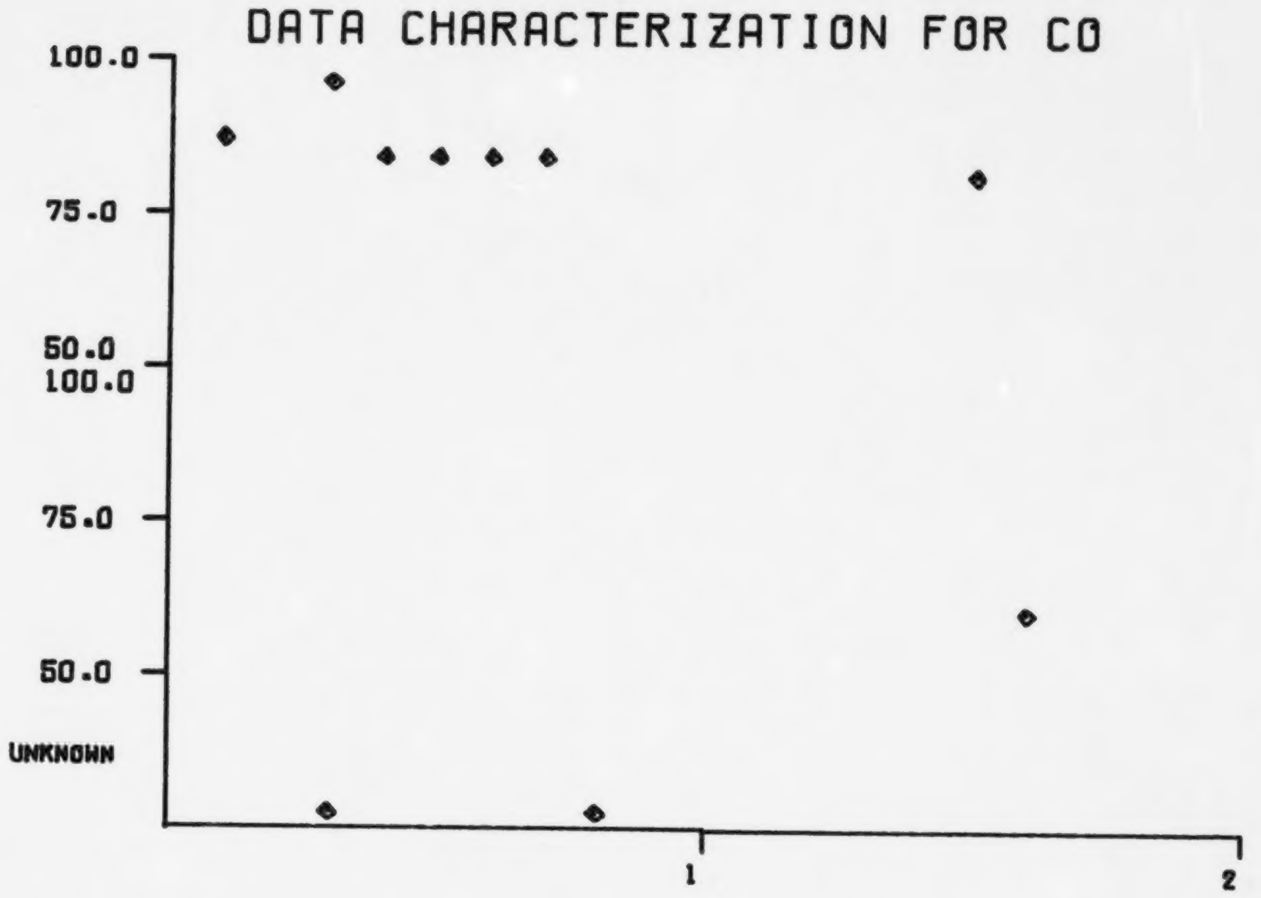
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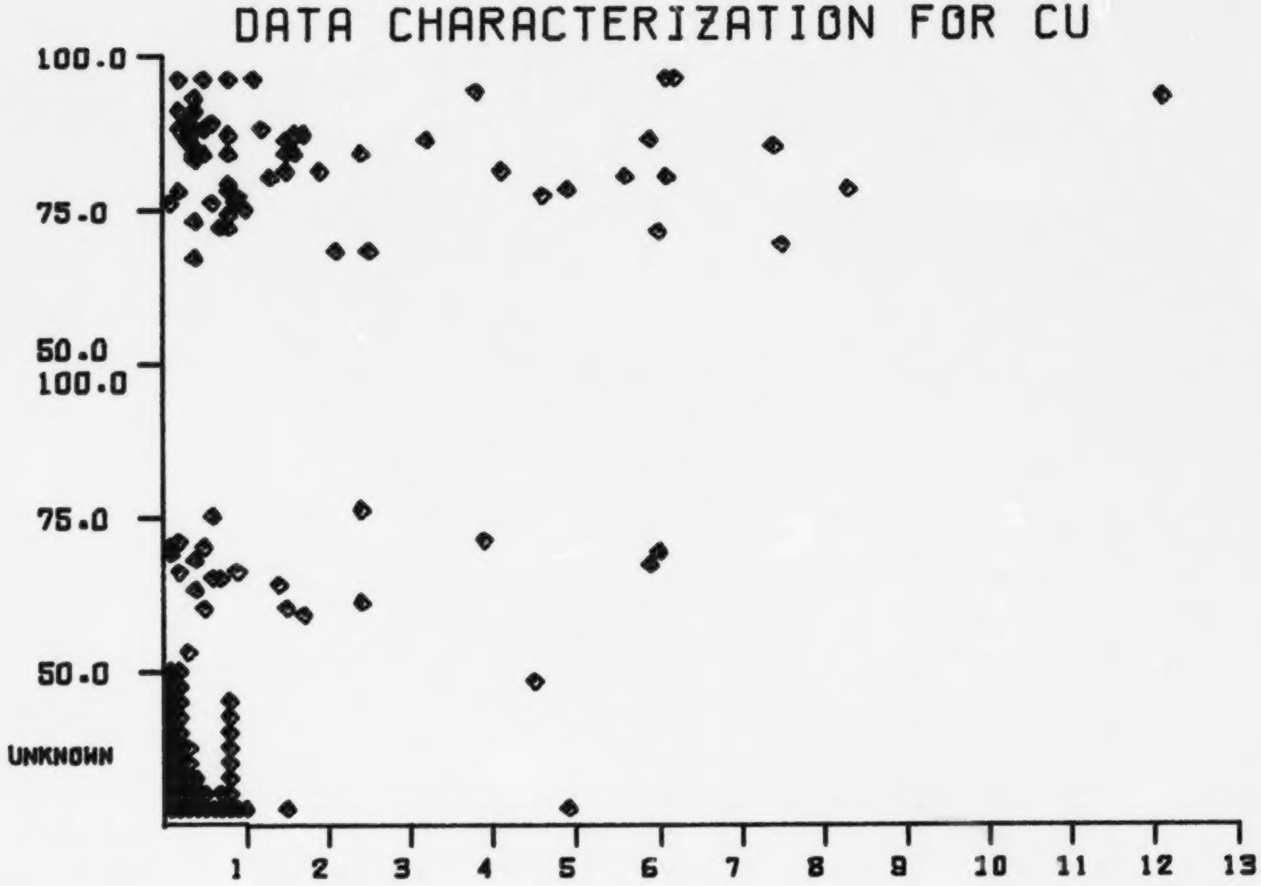
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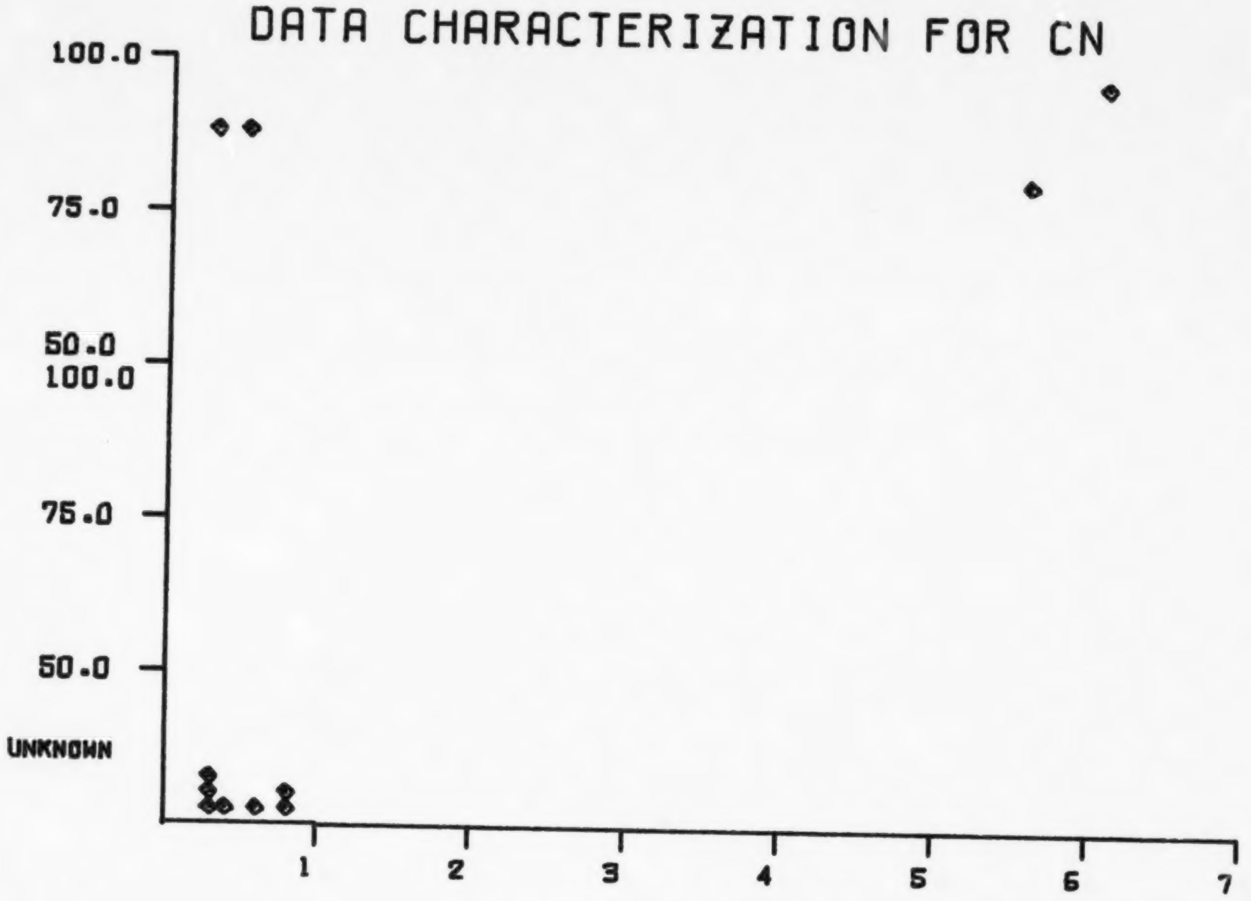
DATA CHARACTERIZATION FOR CN

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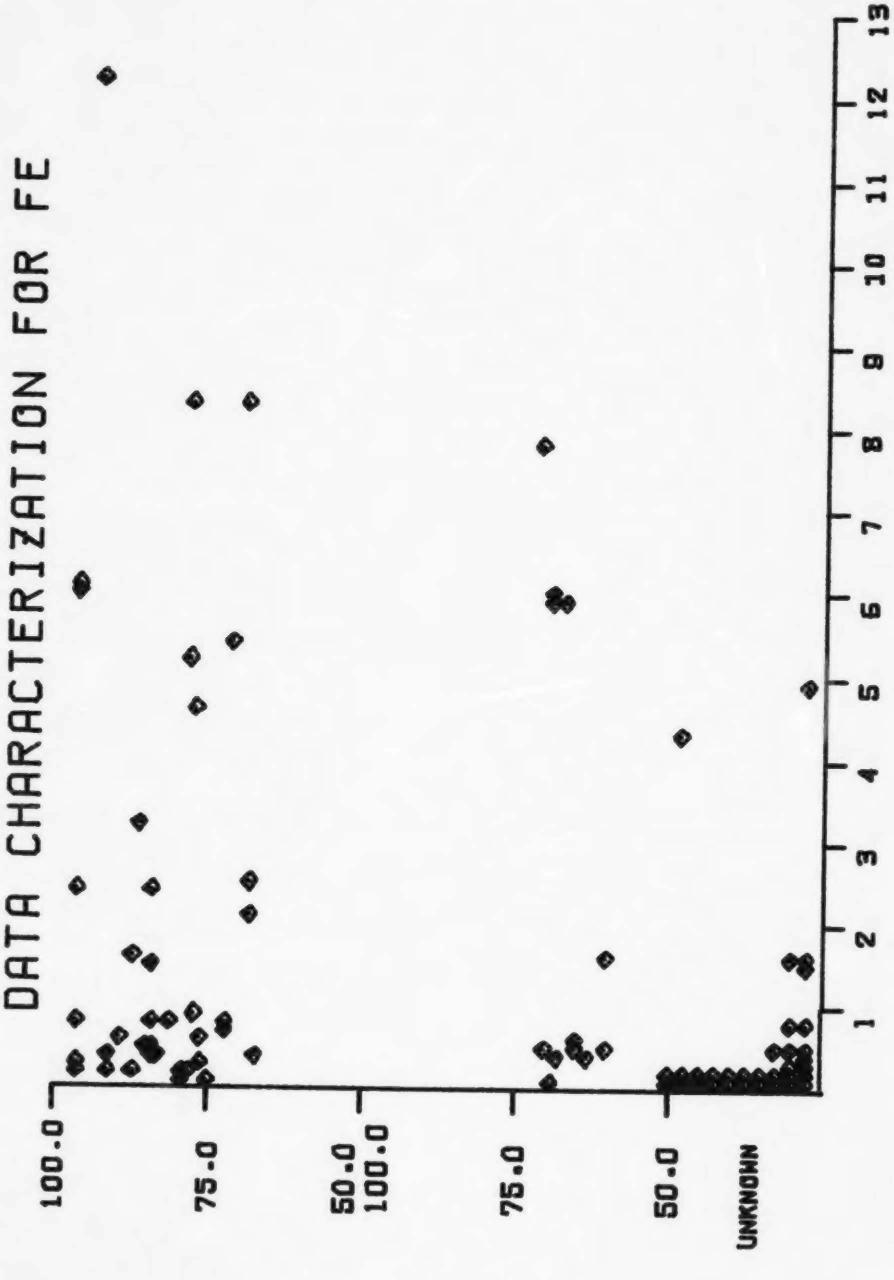

DATA CHARACTERIZATION FOR FE

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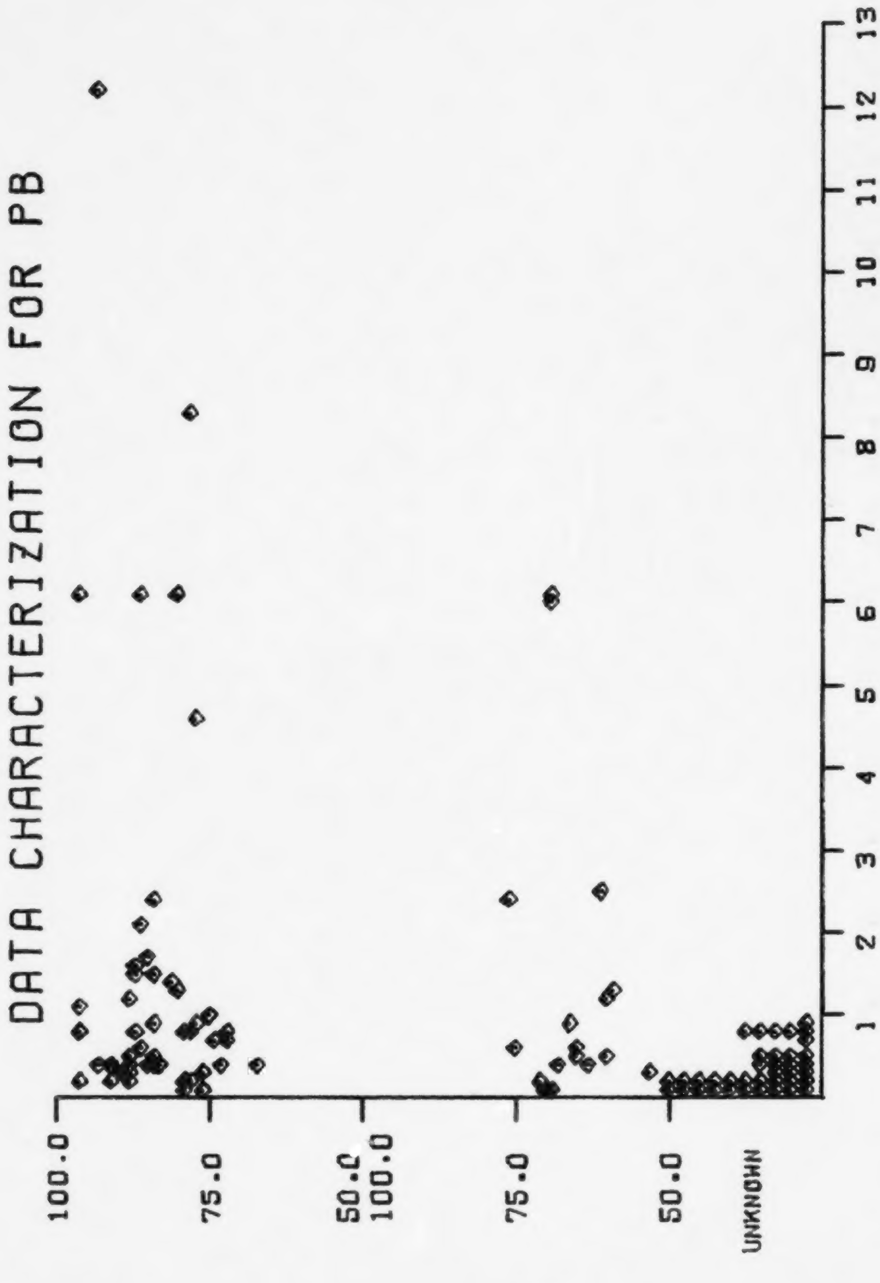
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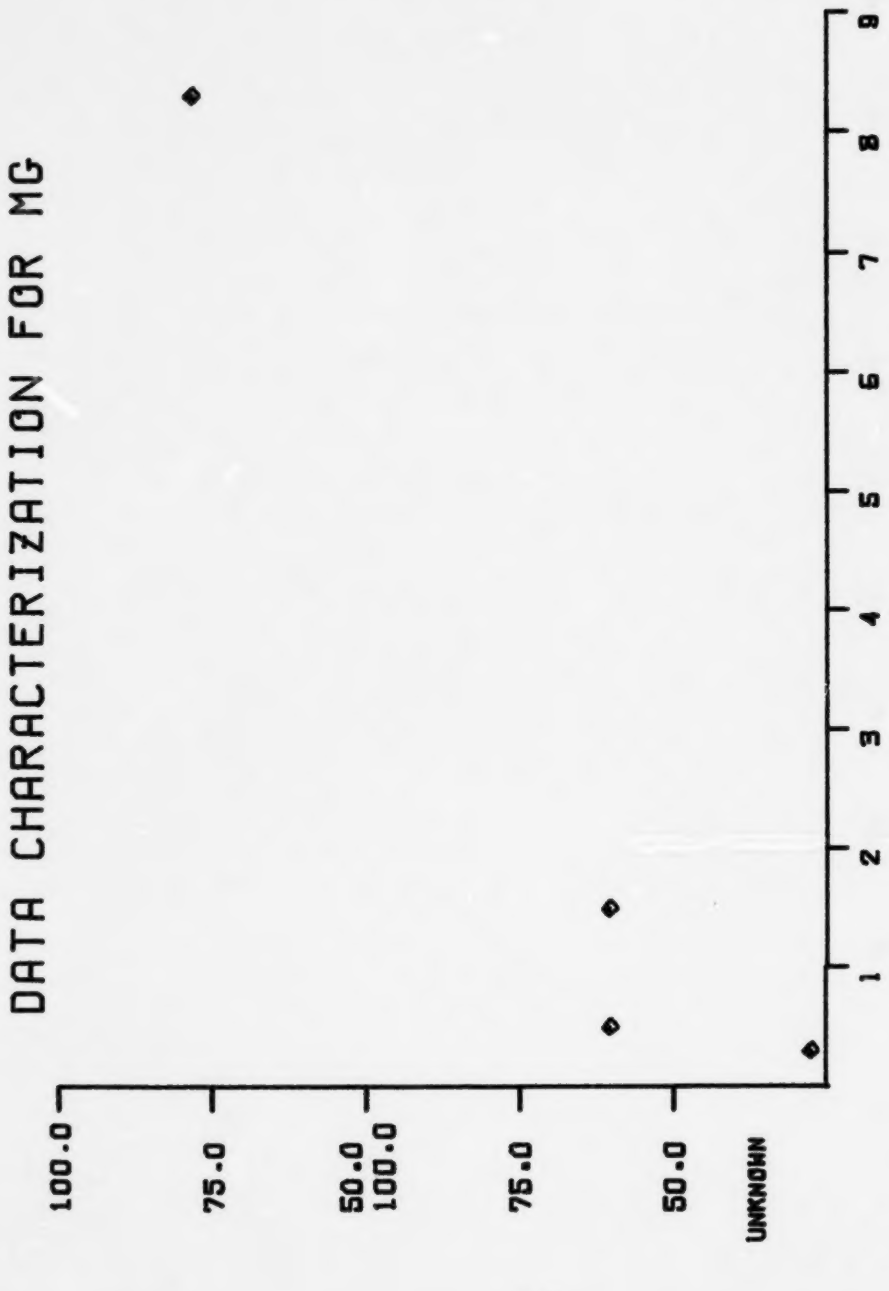
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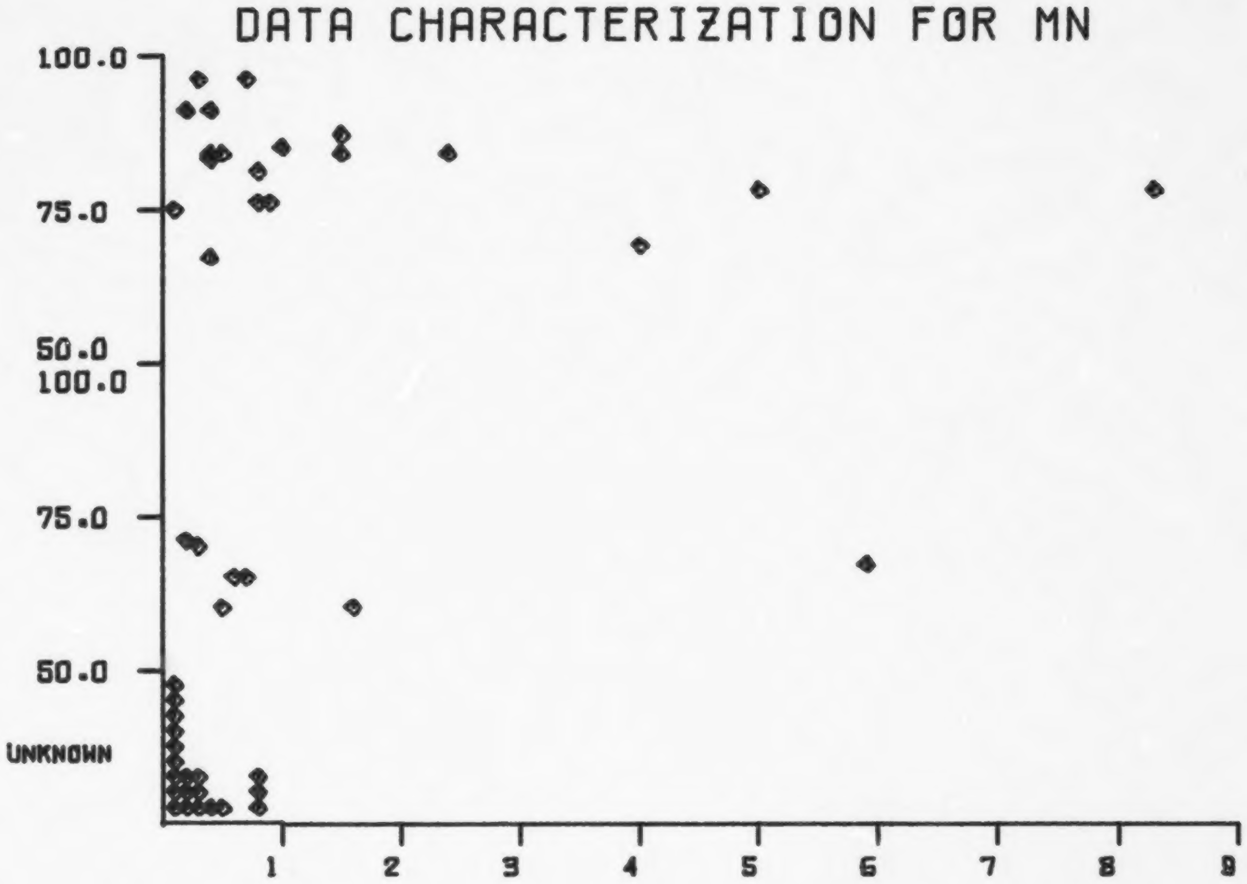
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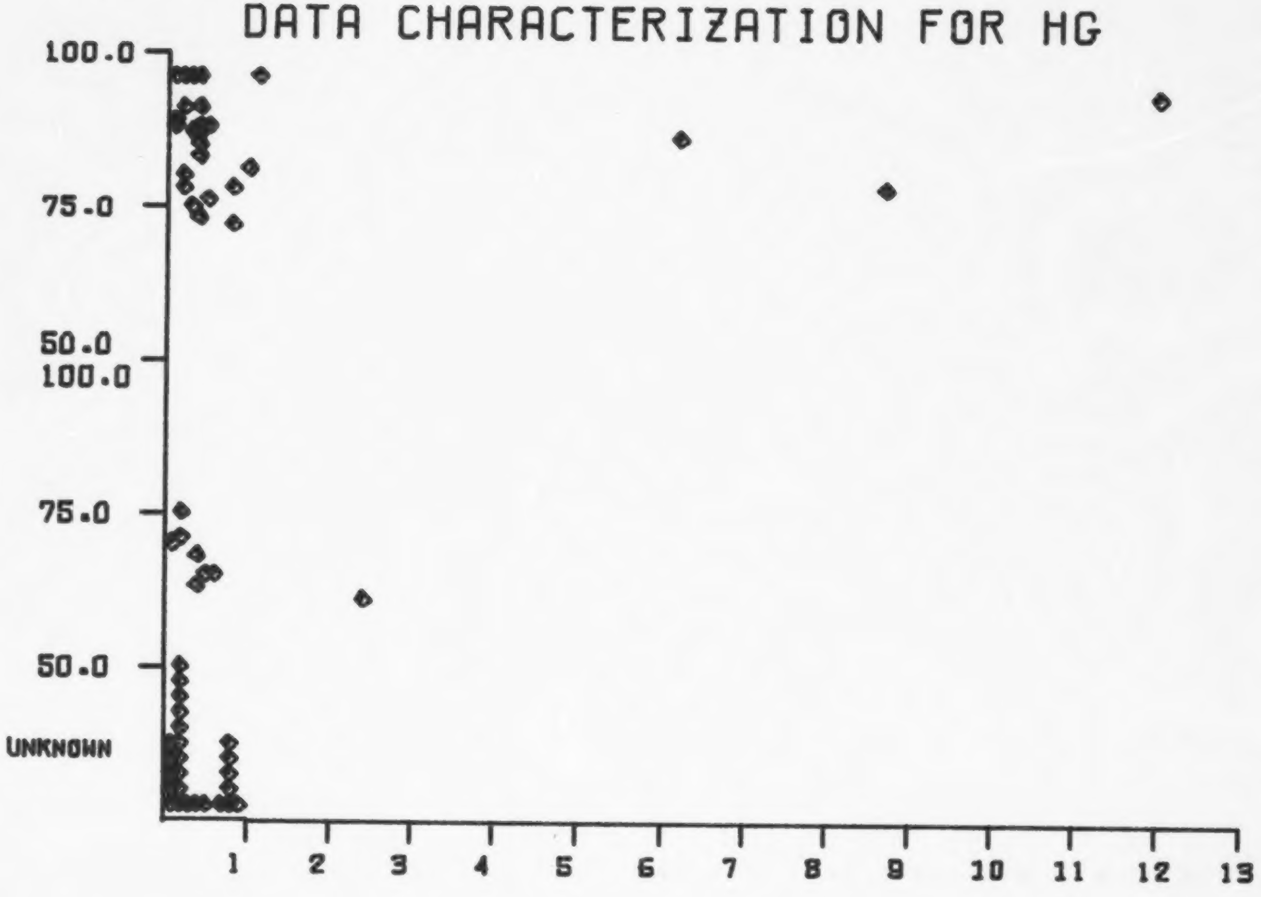
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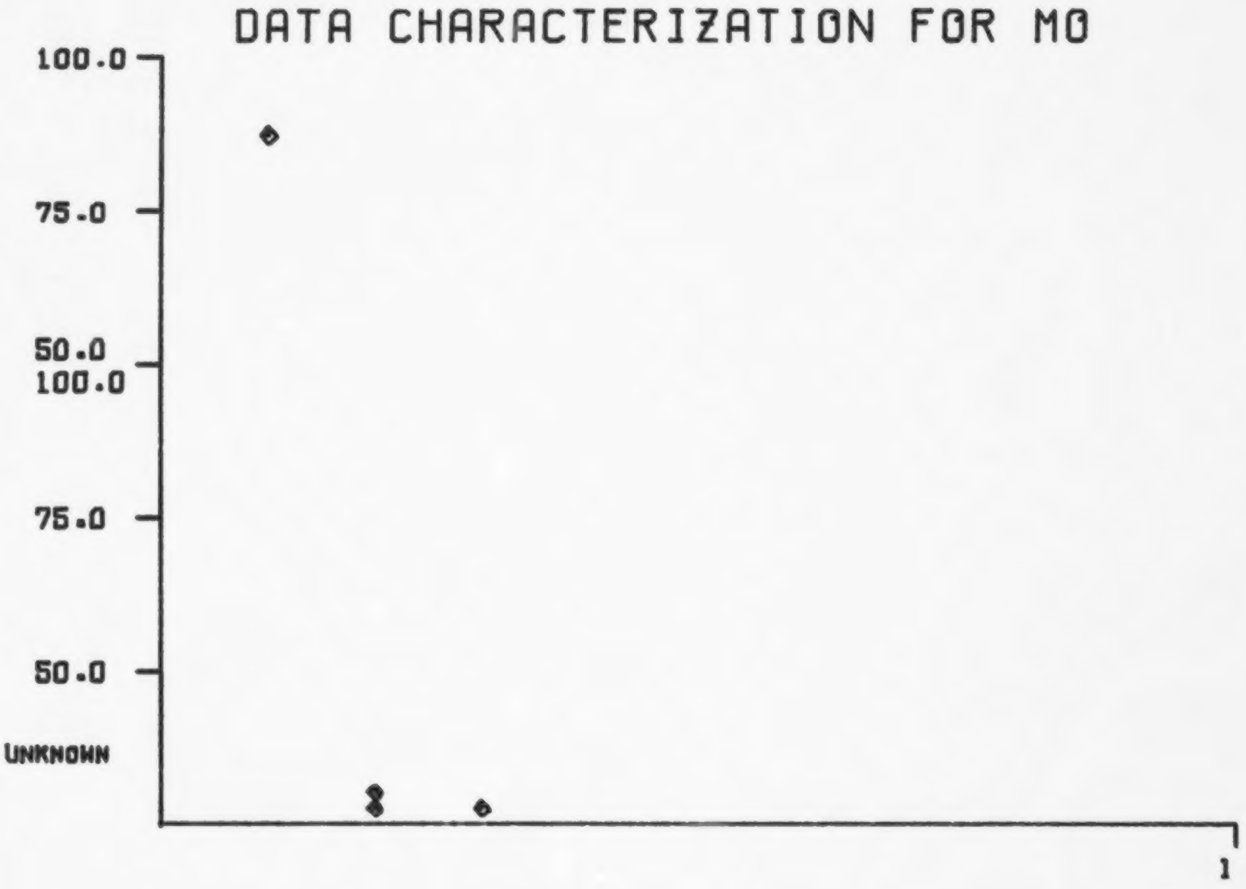
Figure D-19.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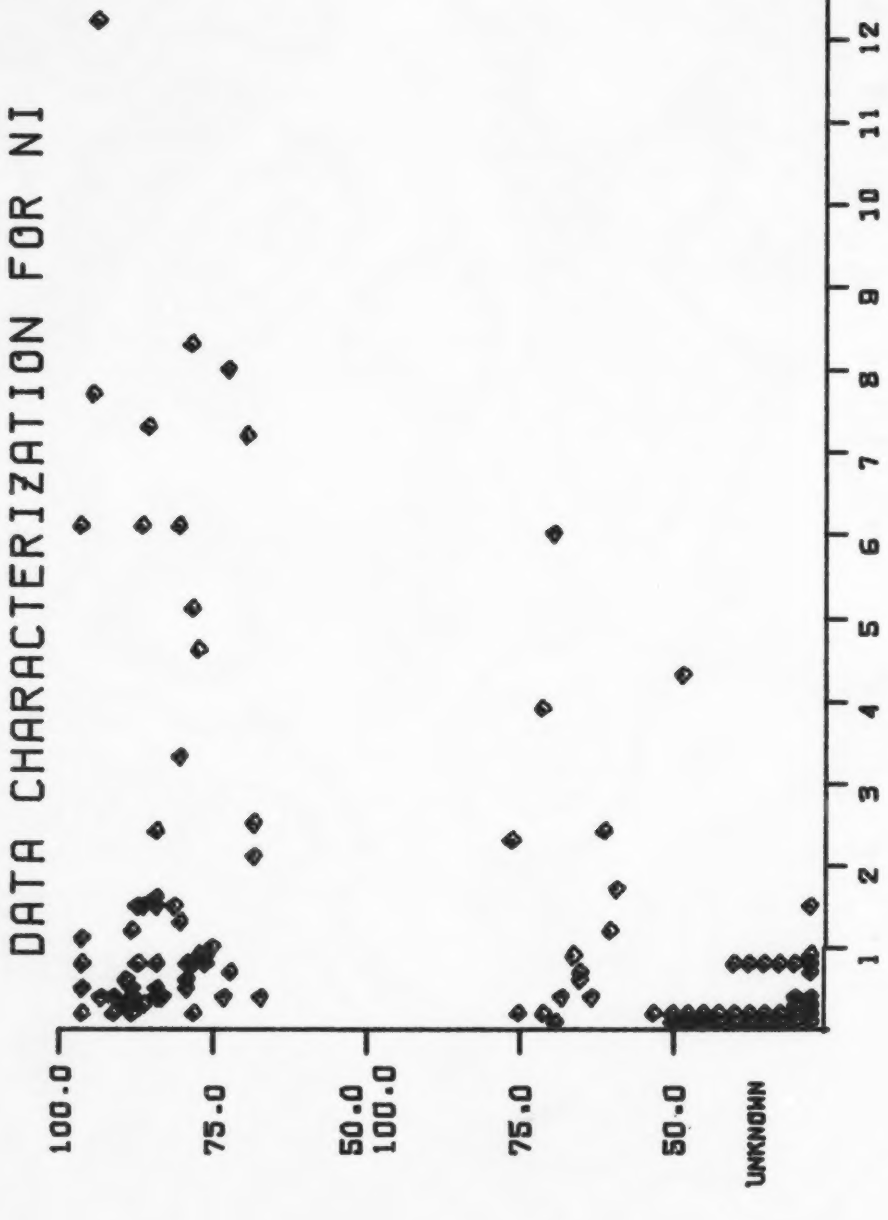
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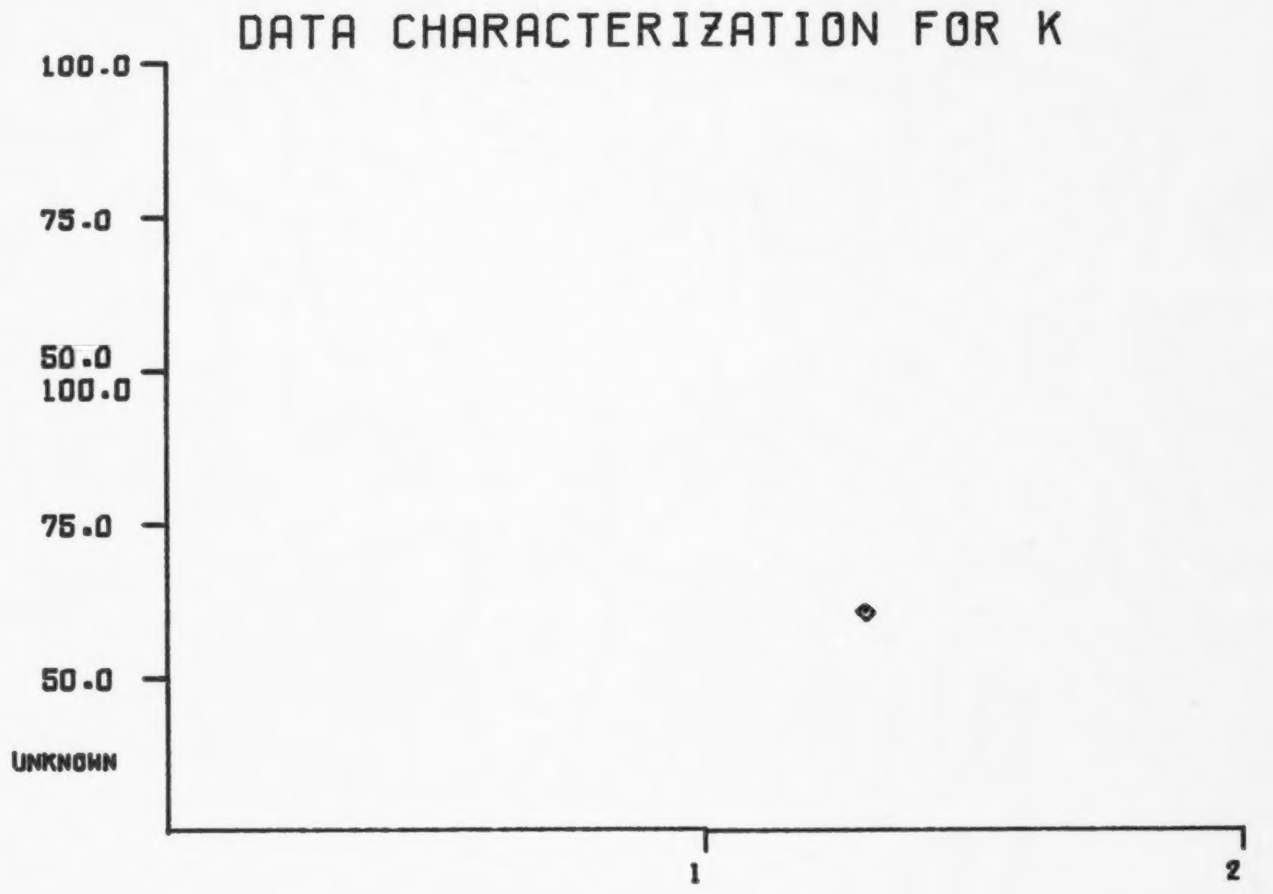
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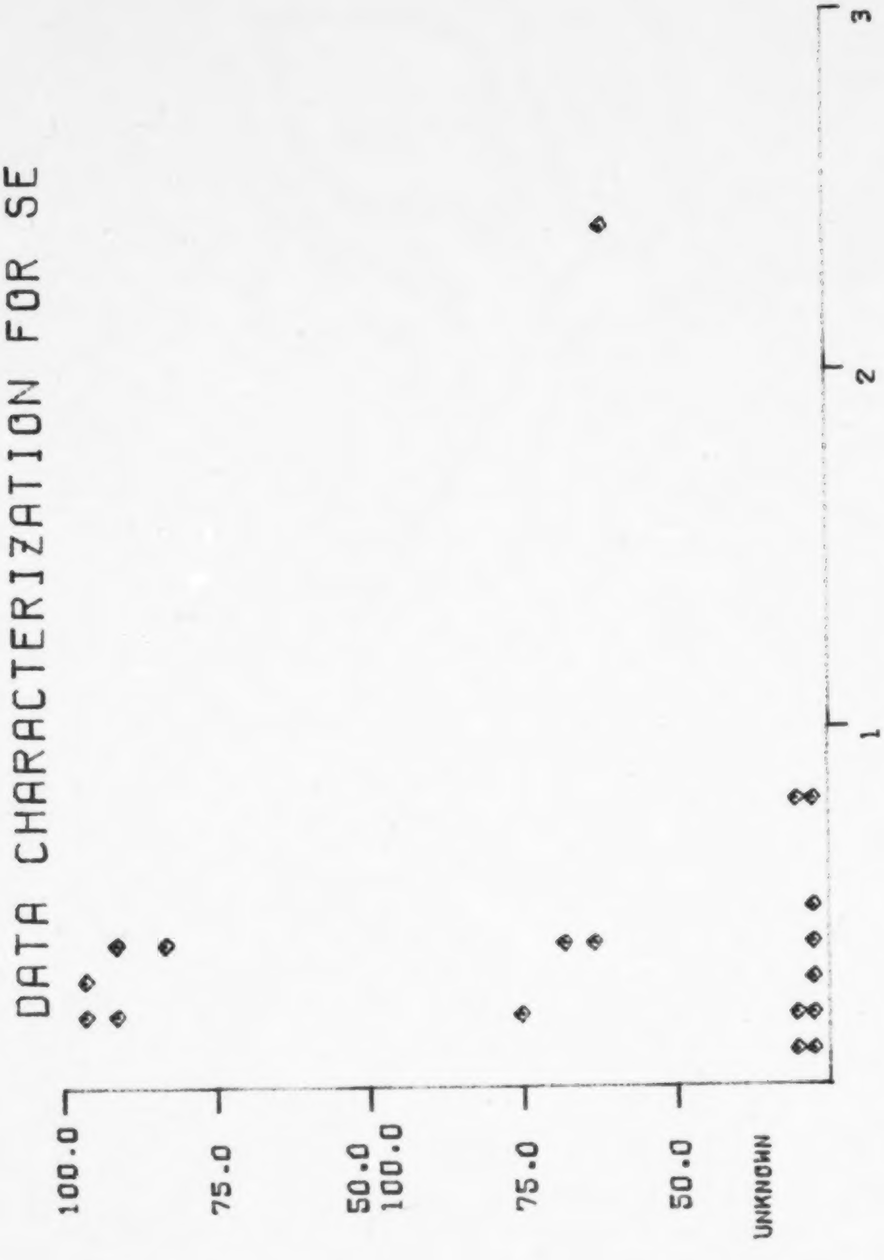

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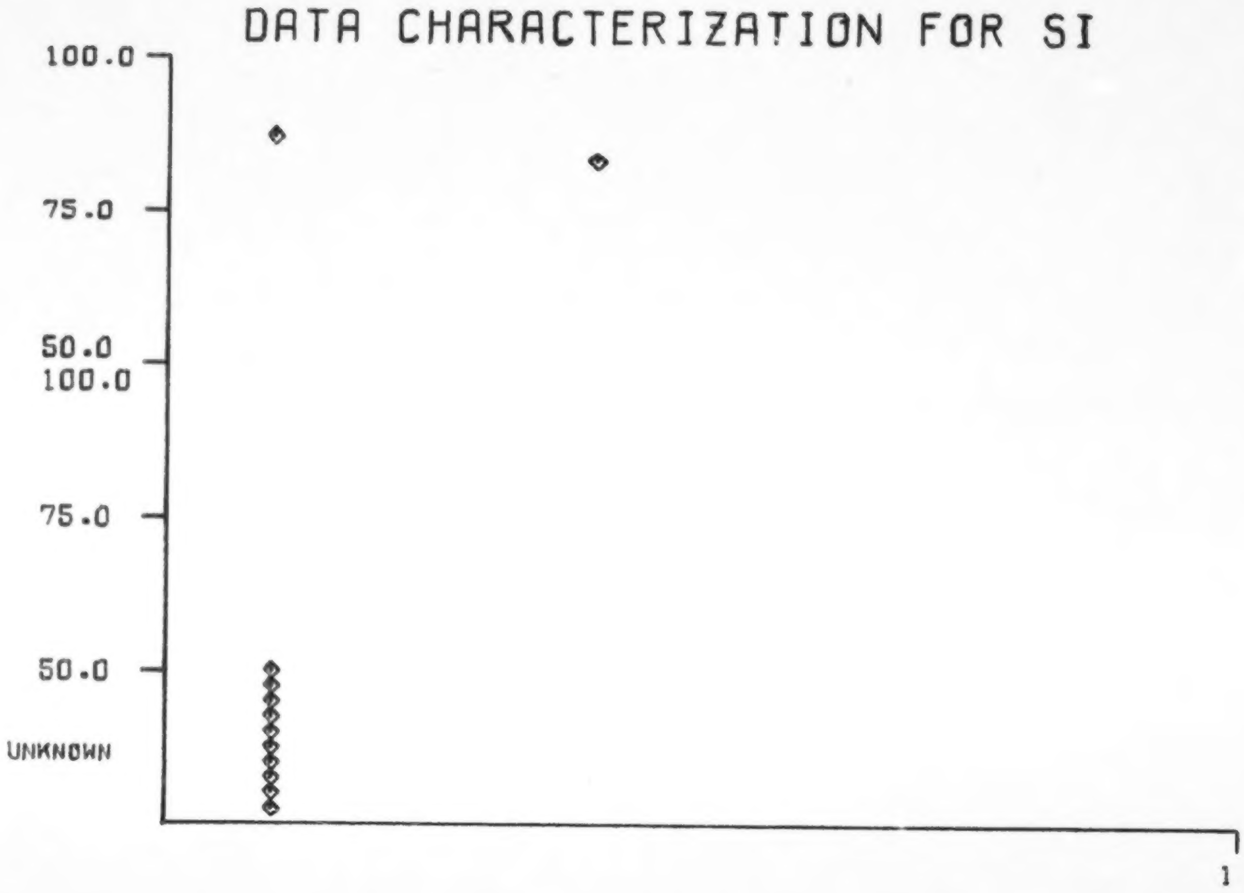
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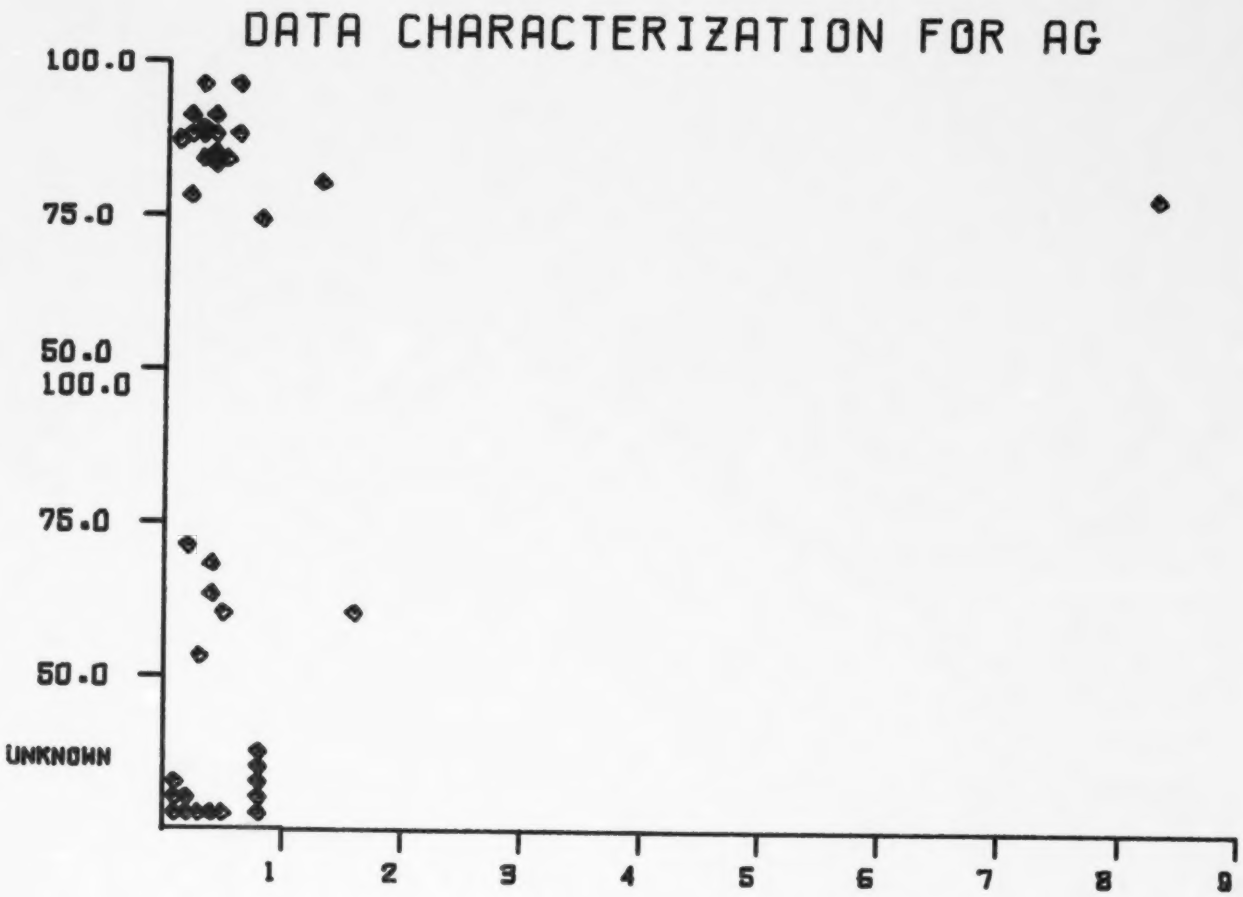
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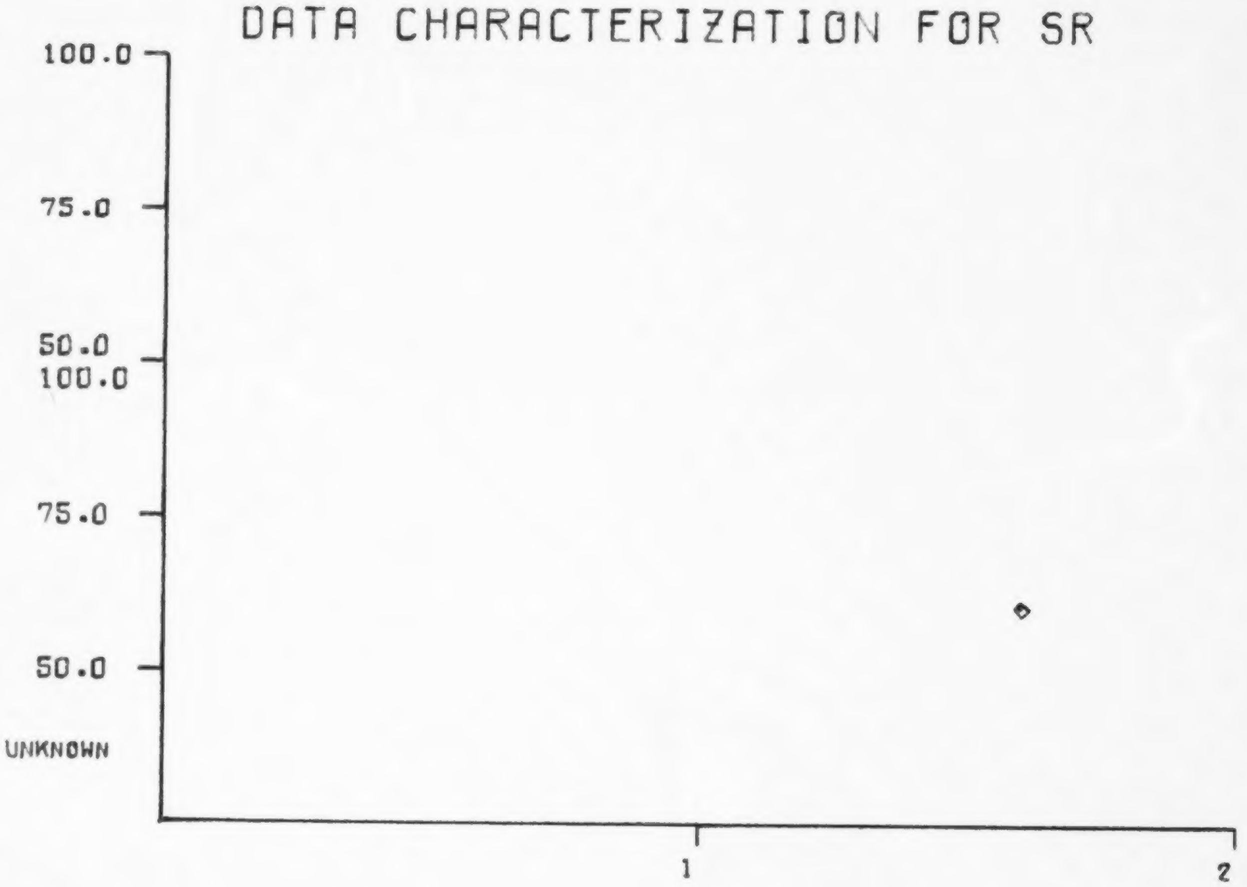
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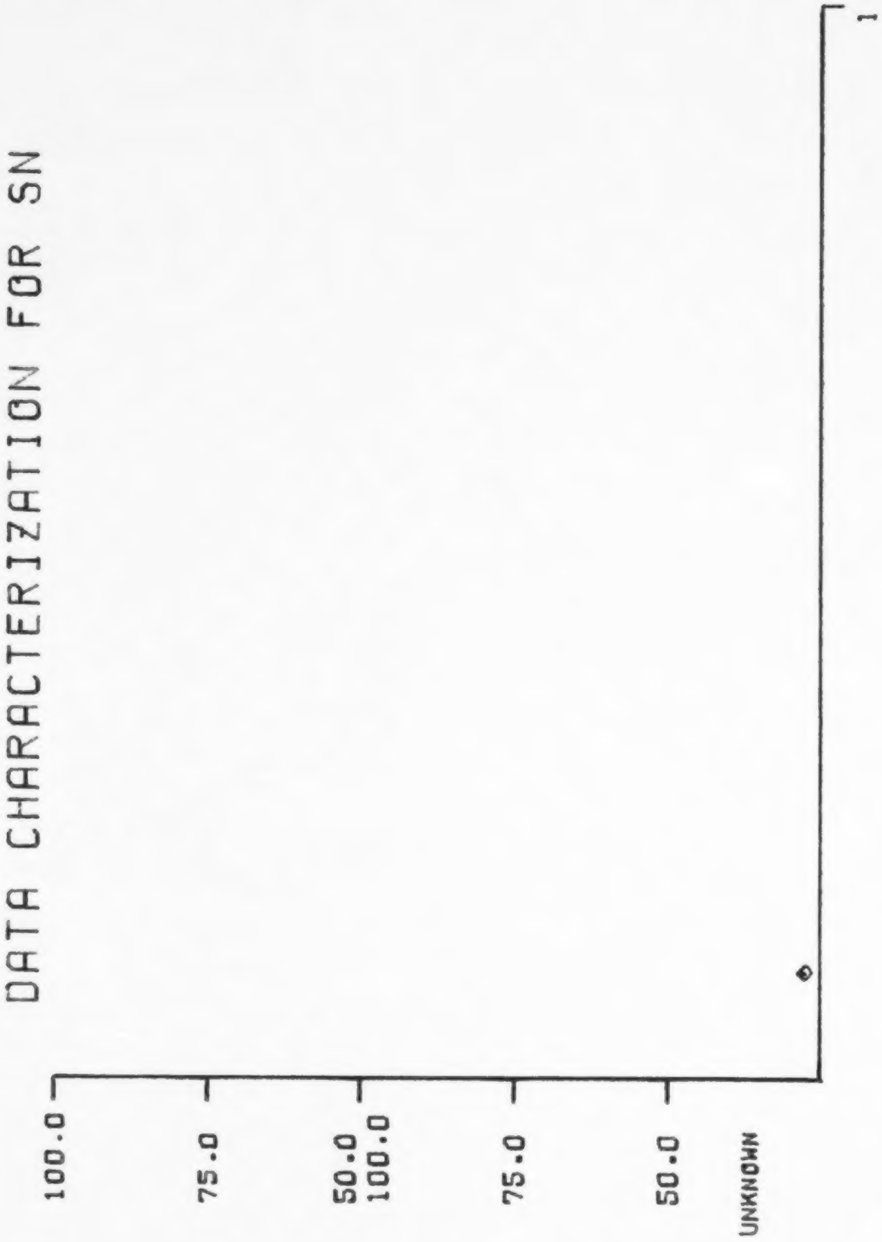
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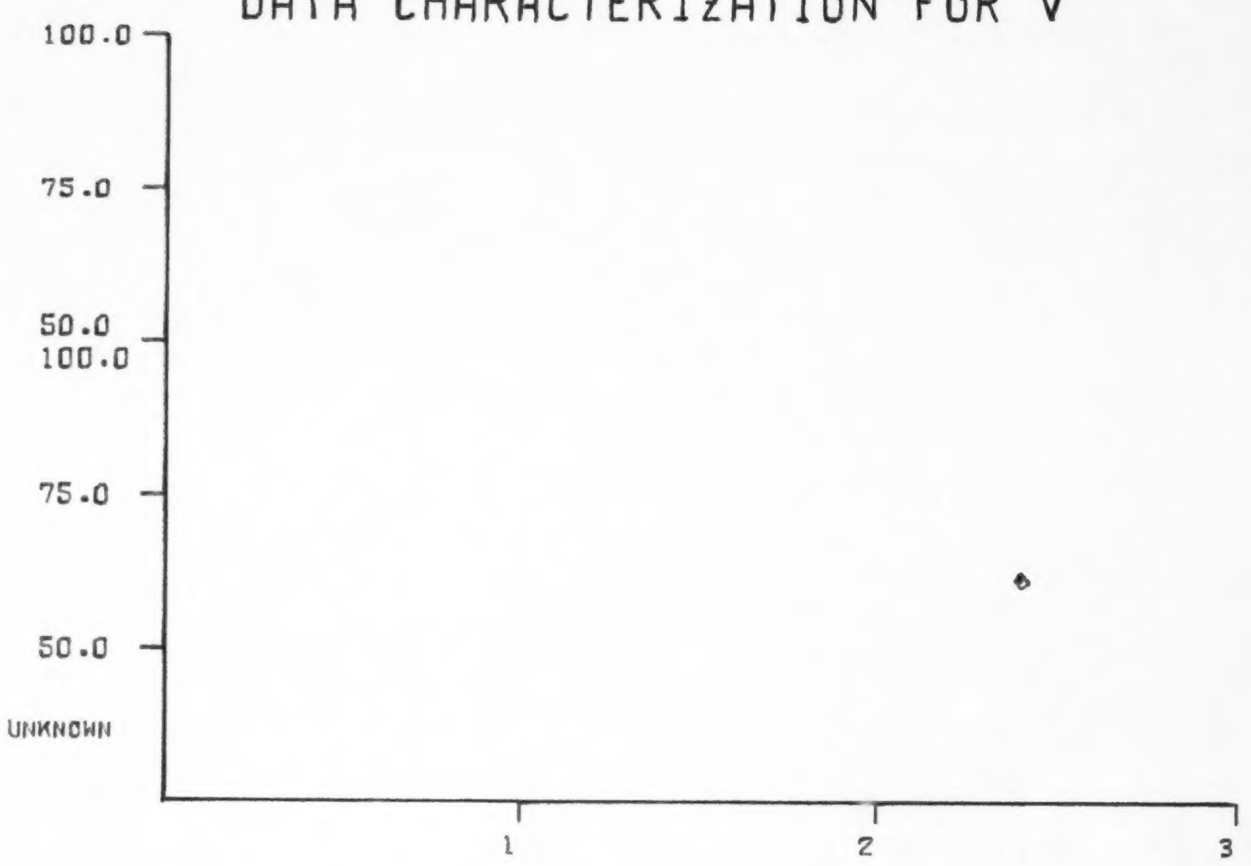
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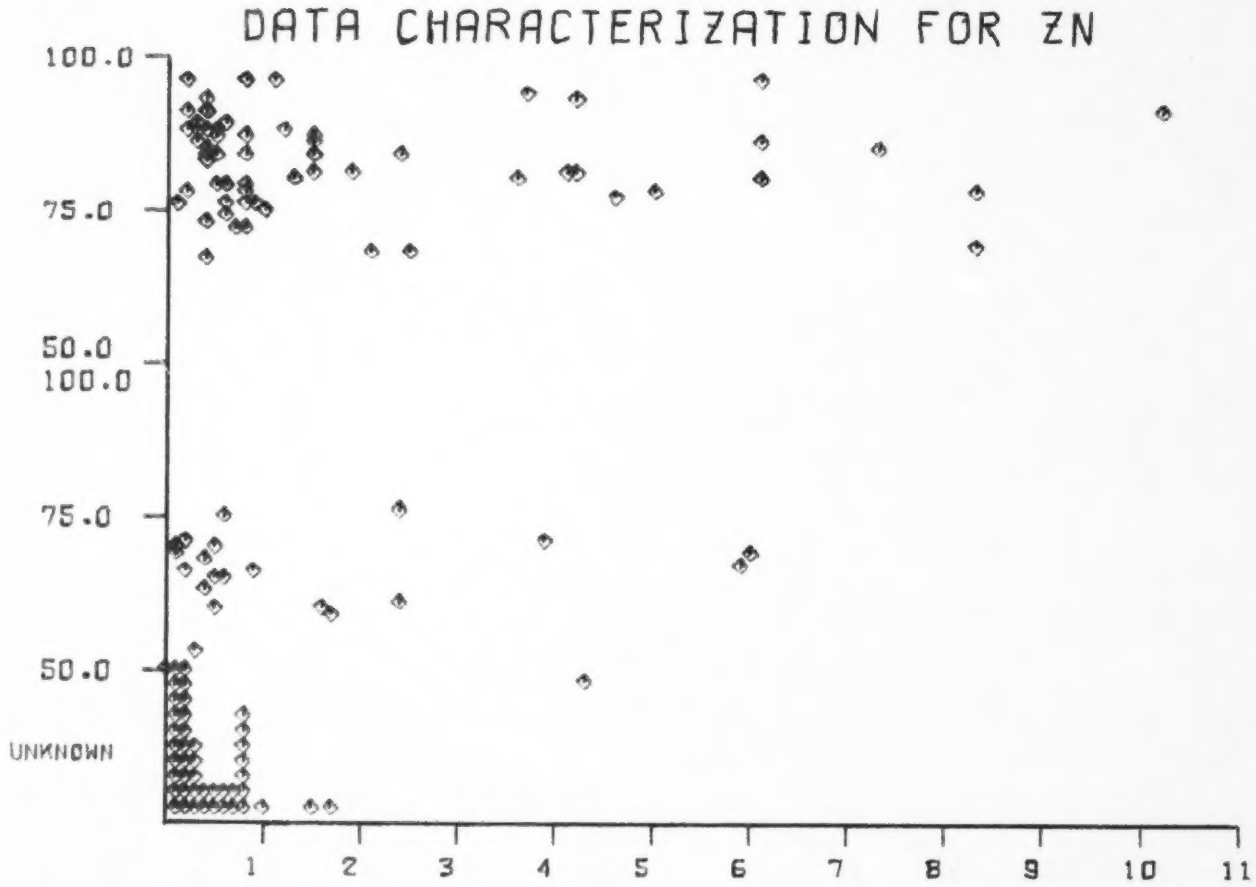
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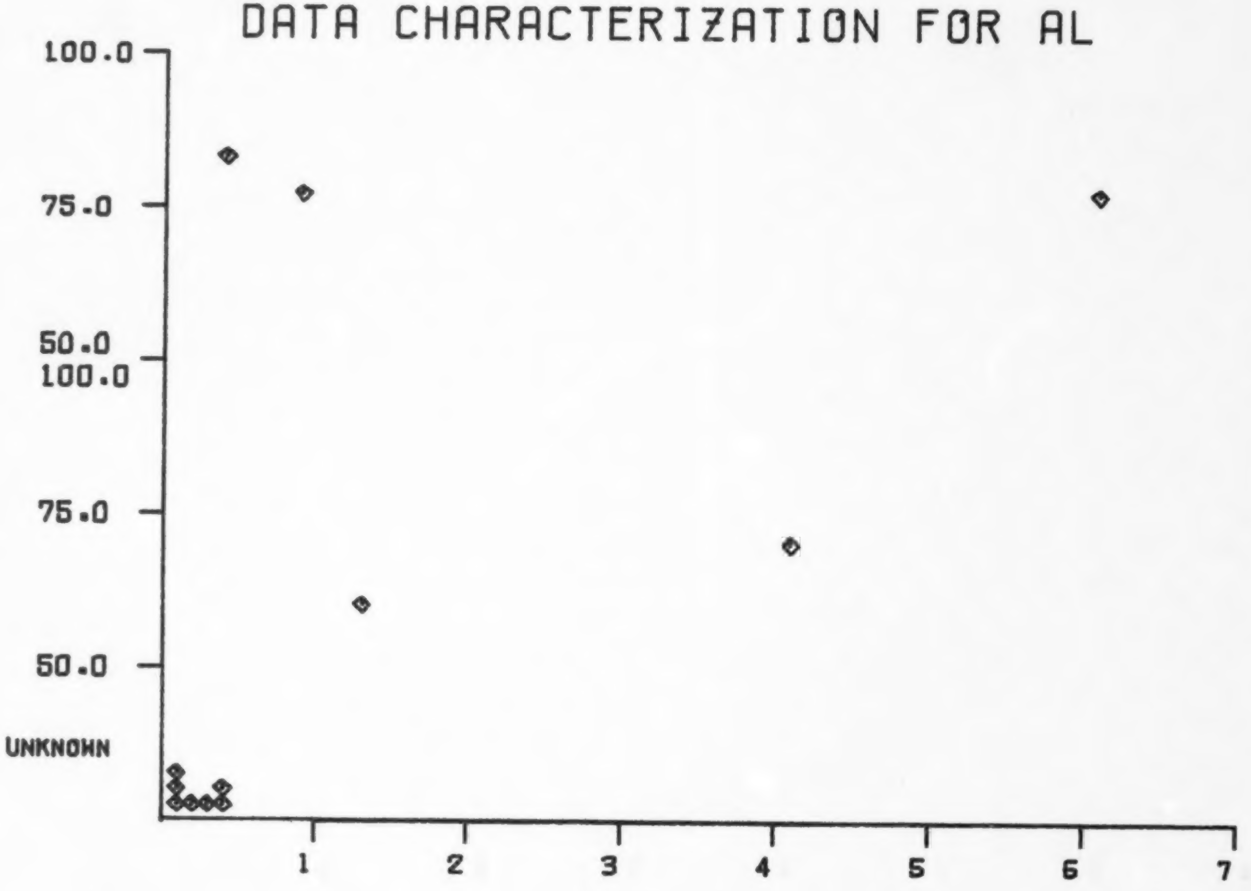
Figure D-29.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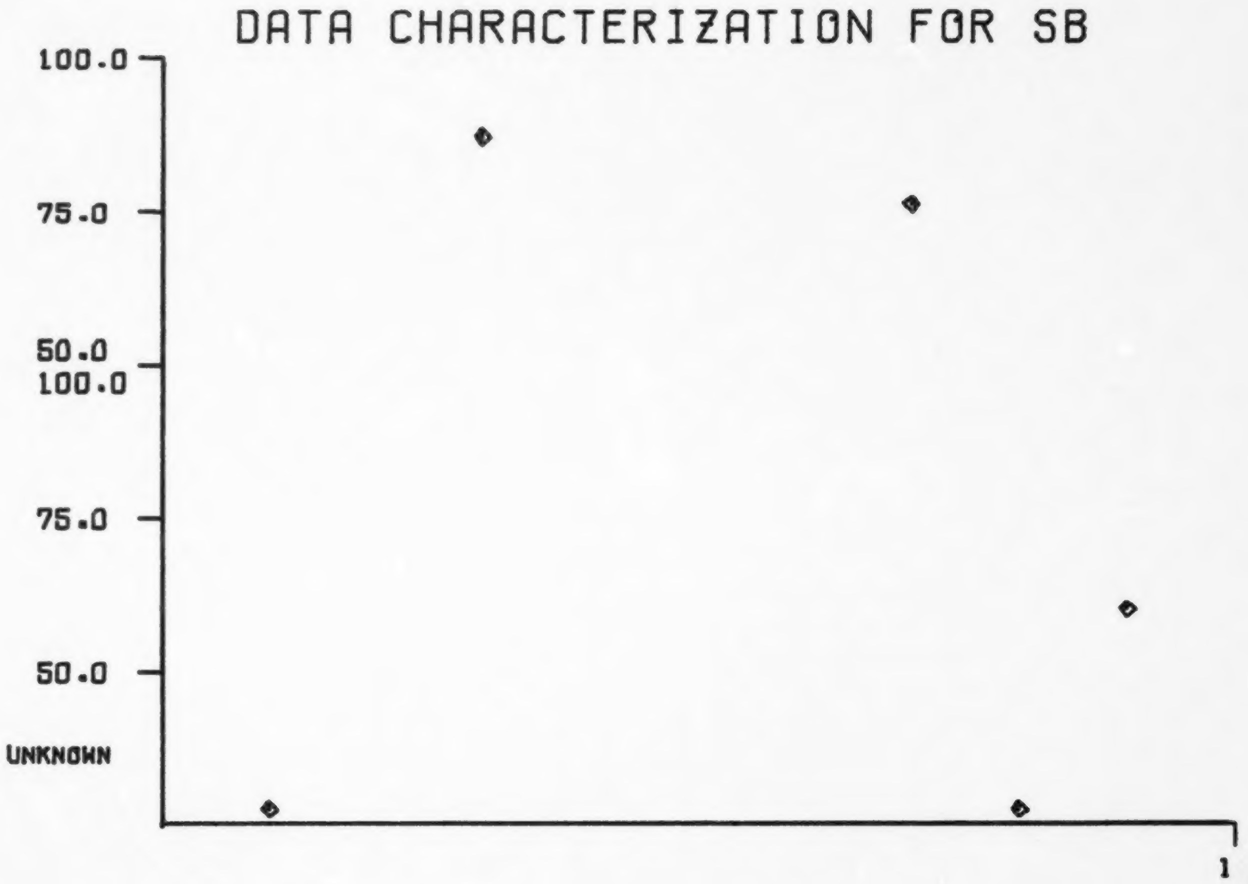
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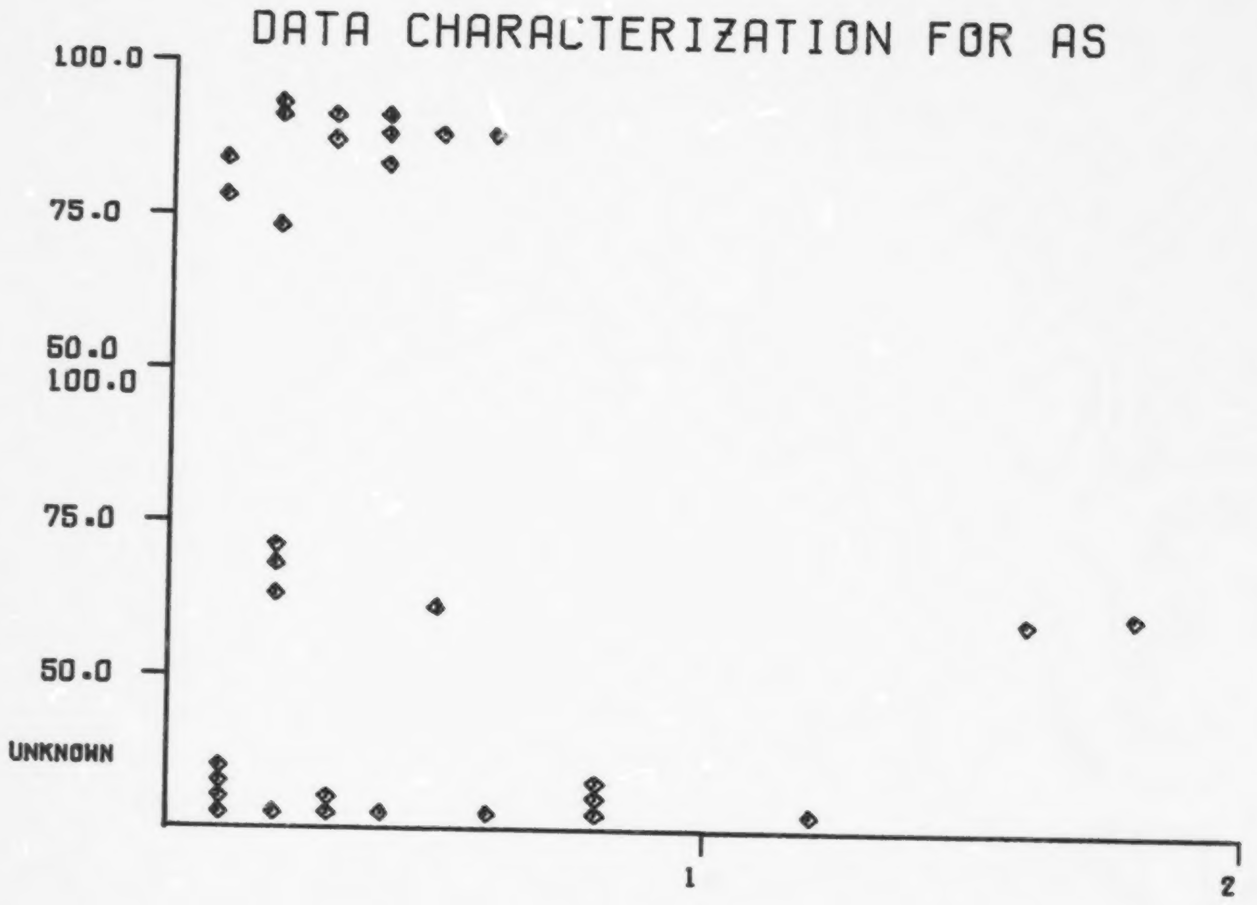
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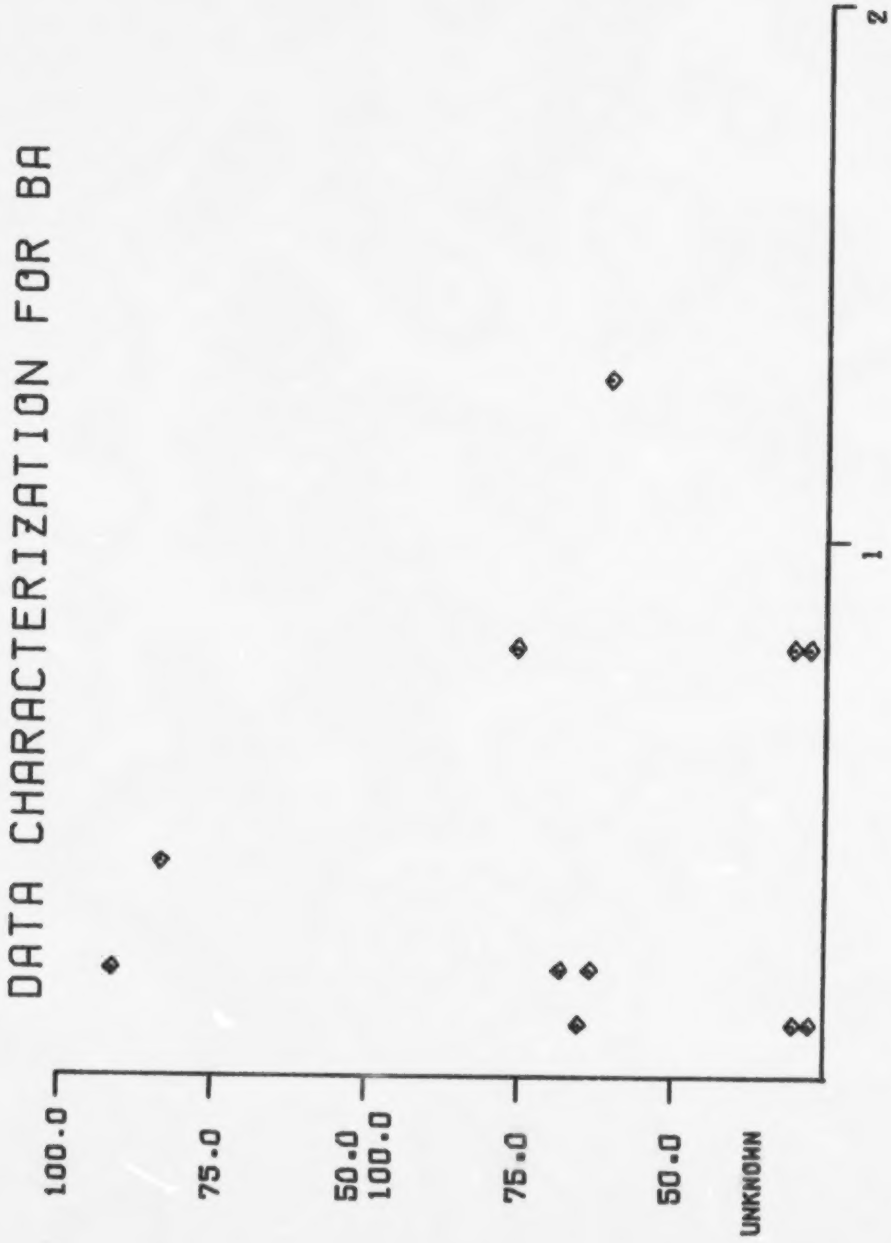
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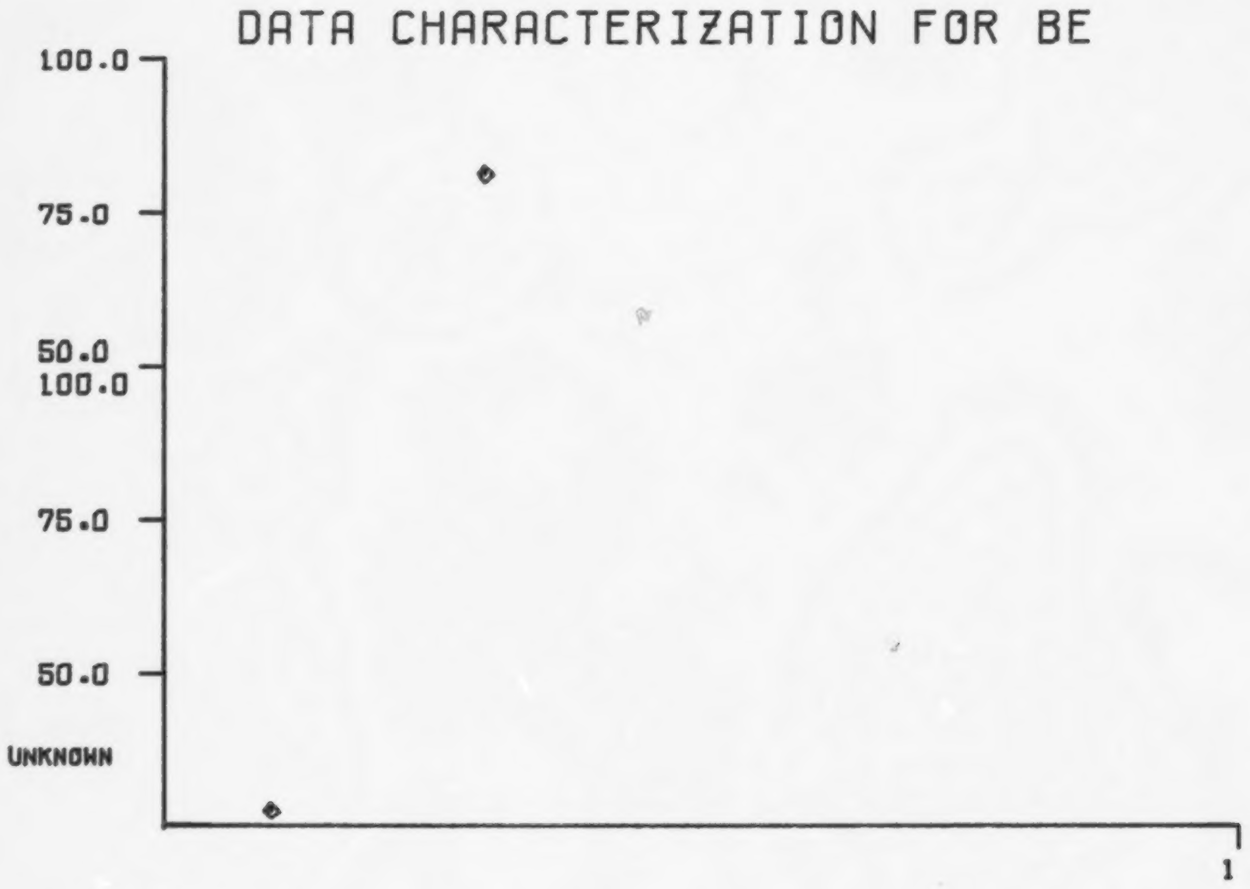
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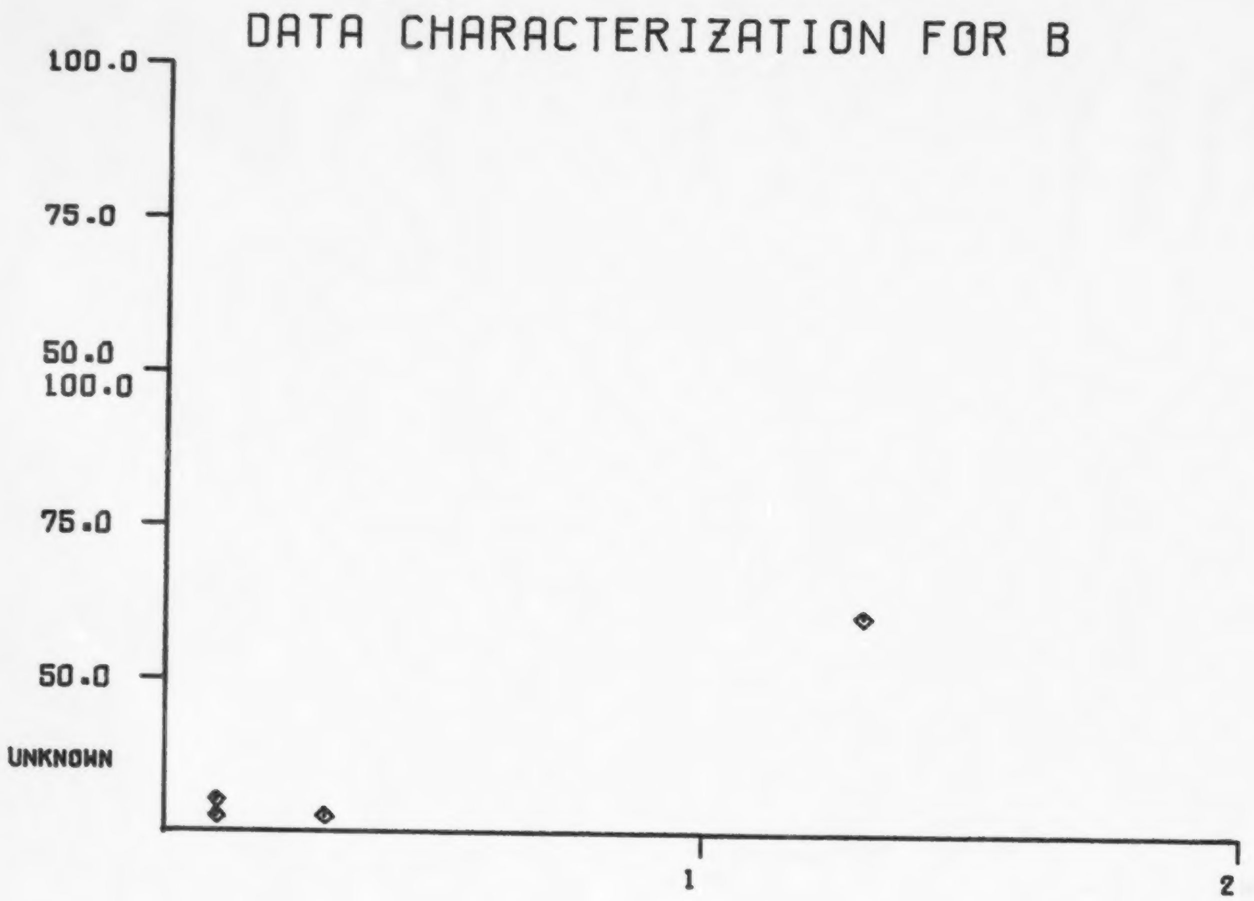
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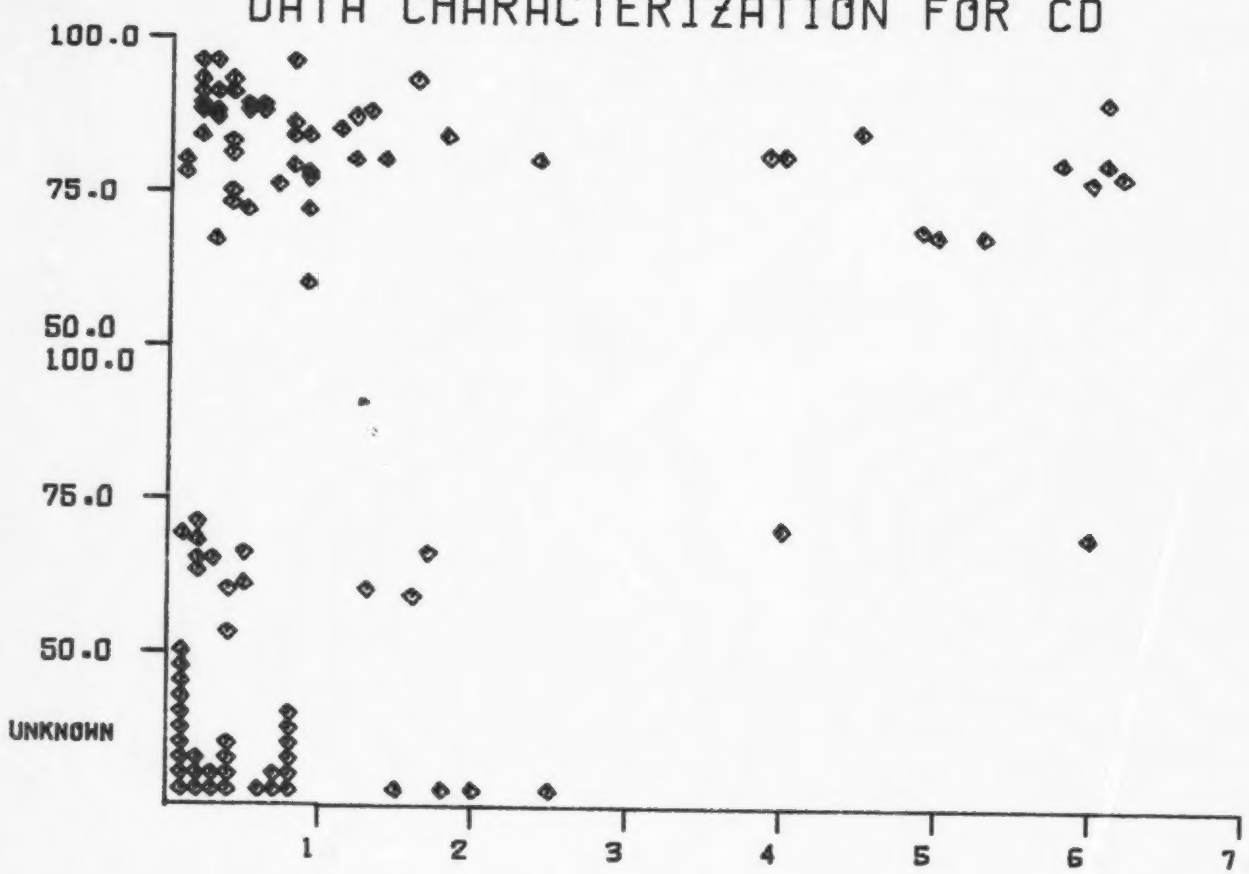
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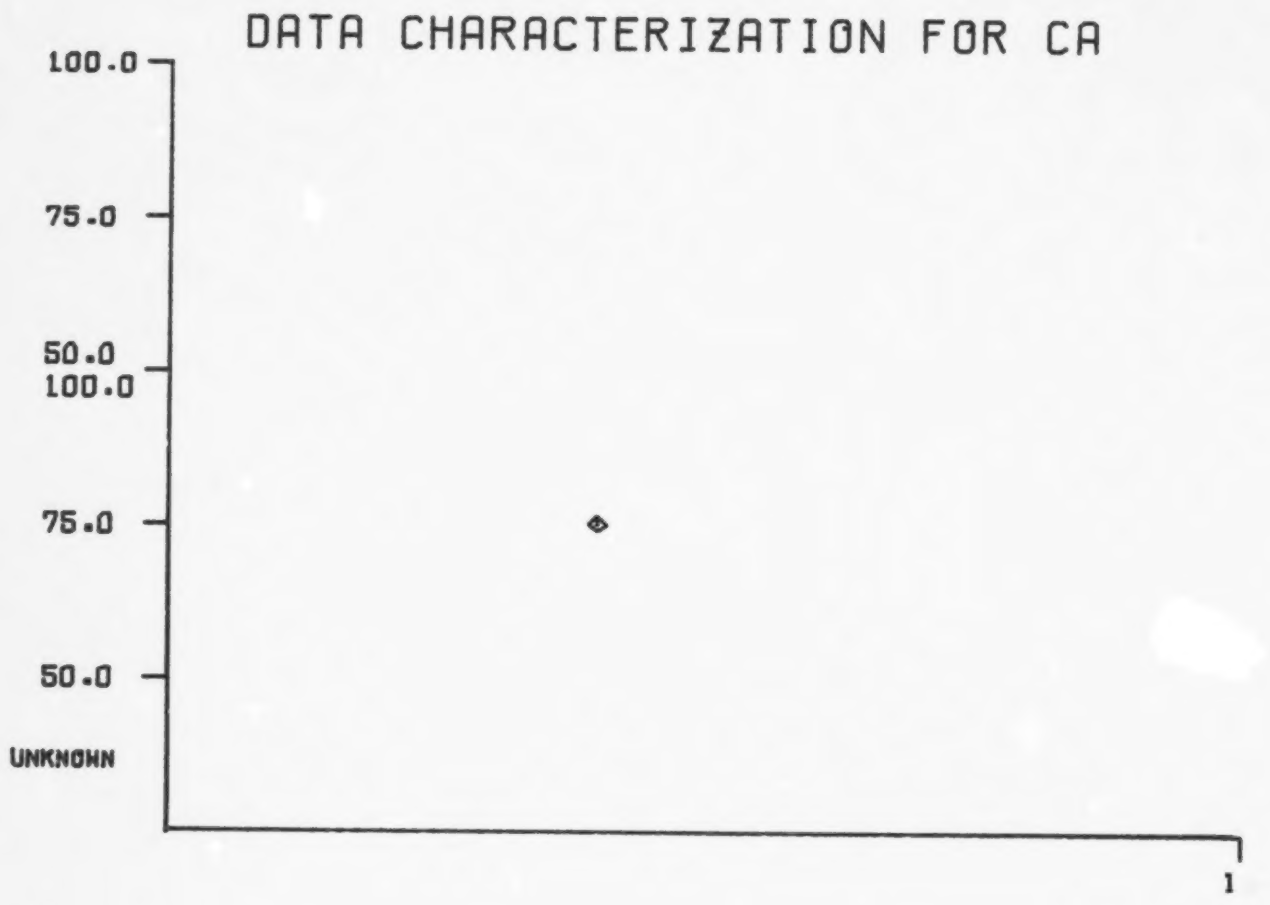
Figure D-36.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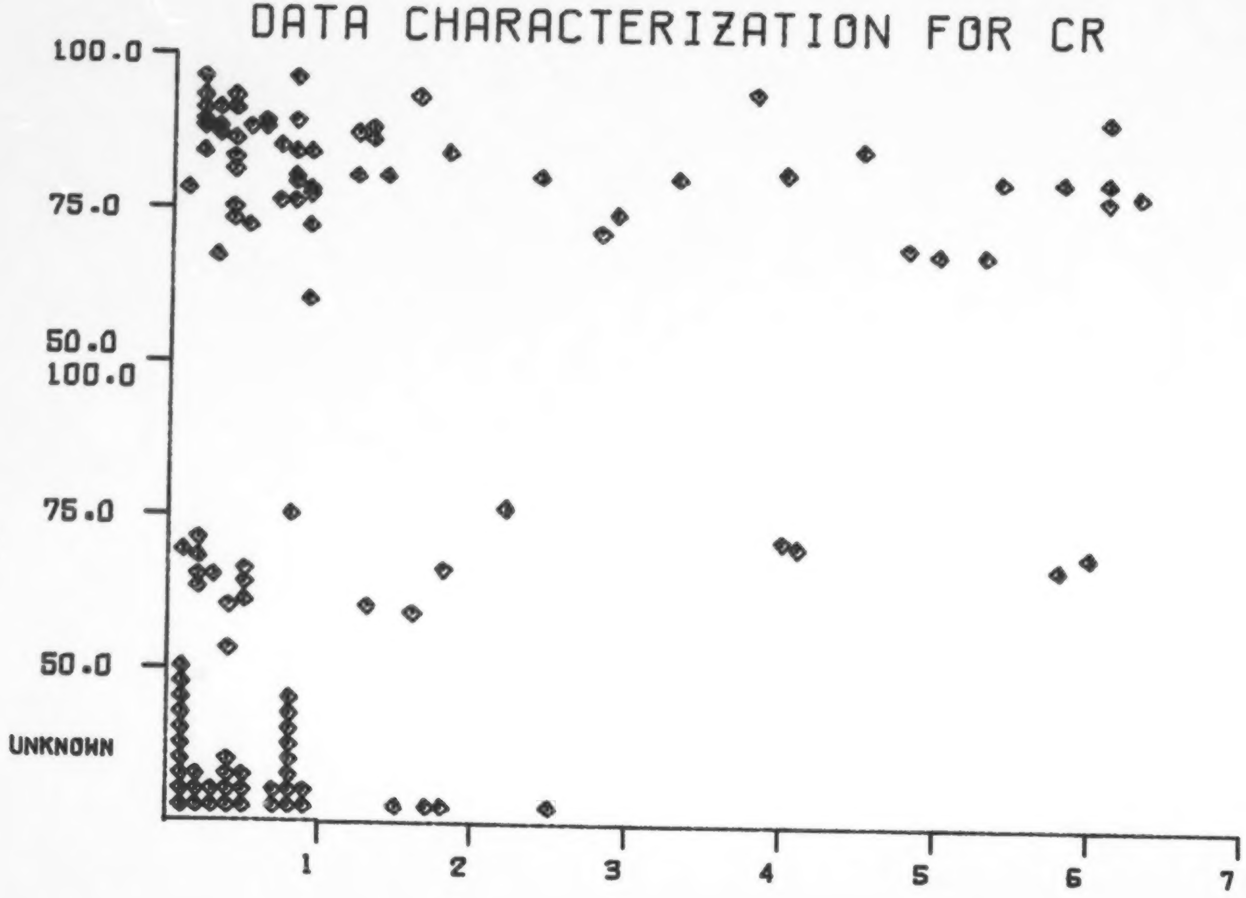
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Figure D-38.

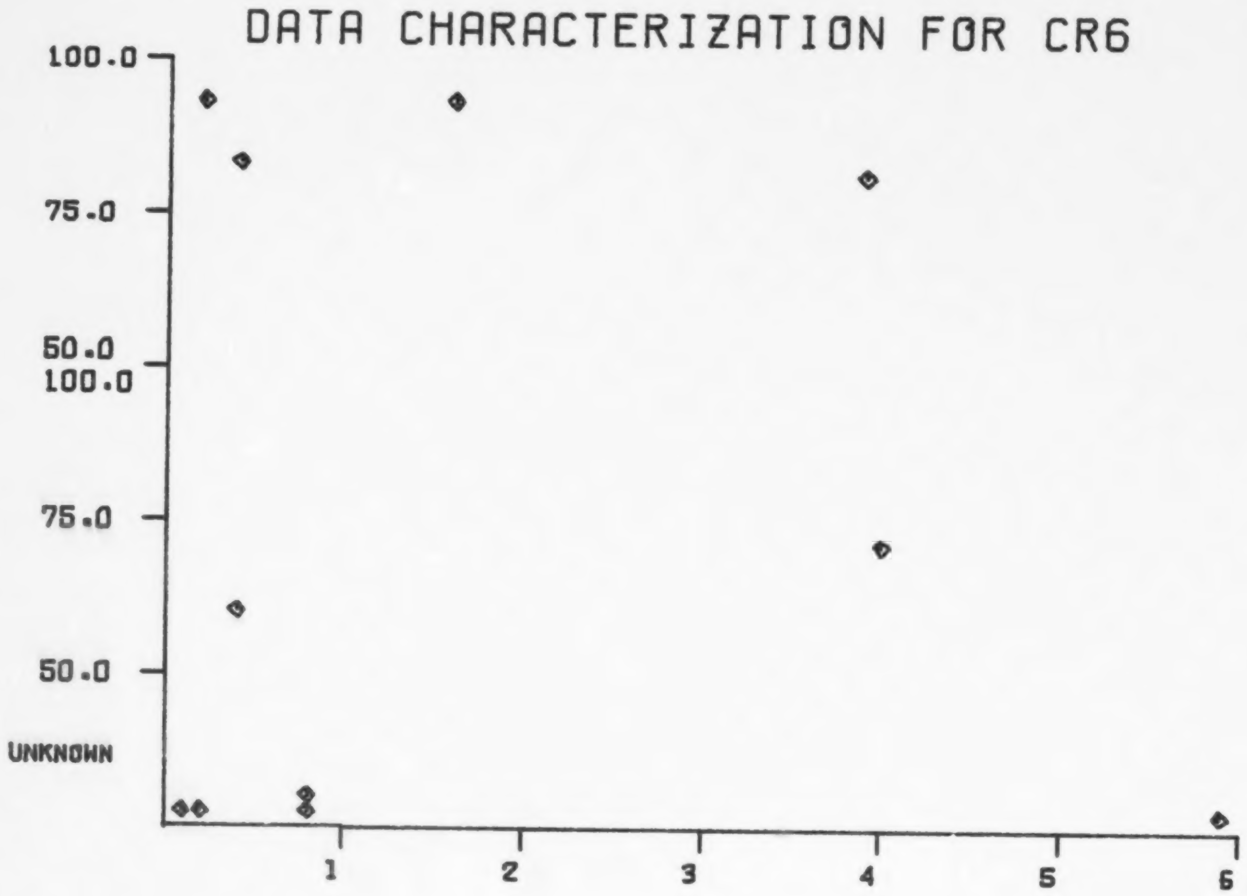
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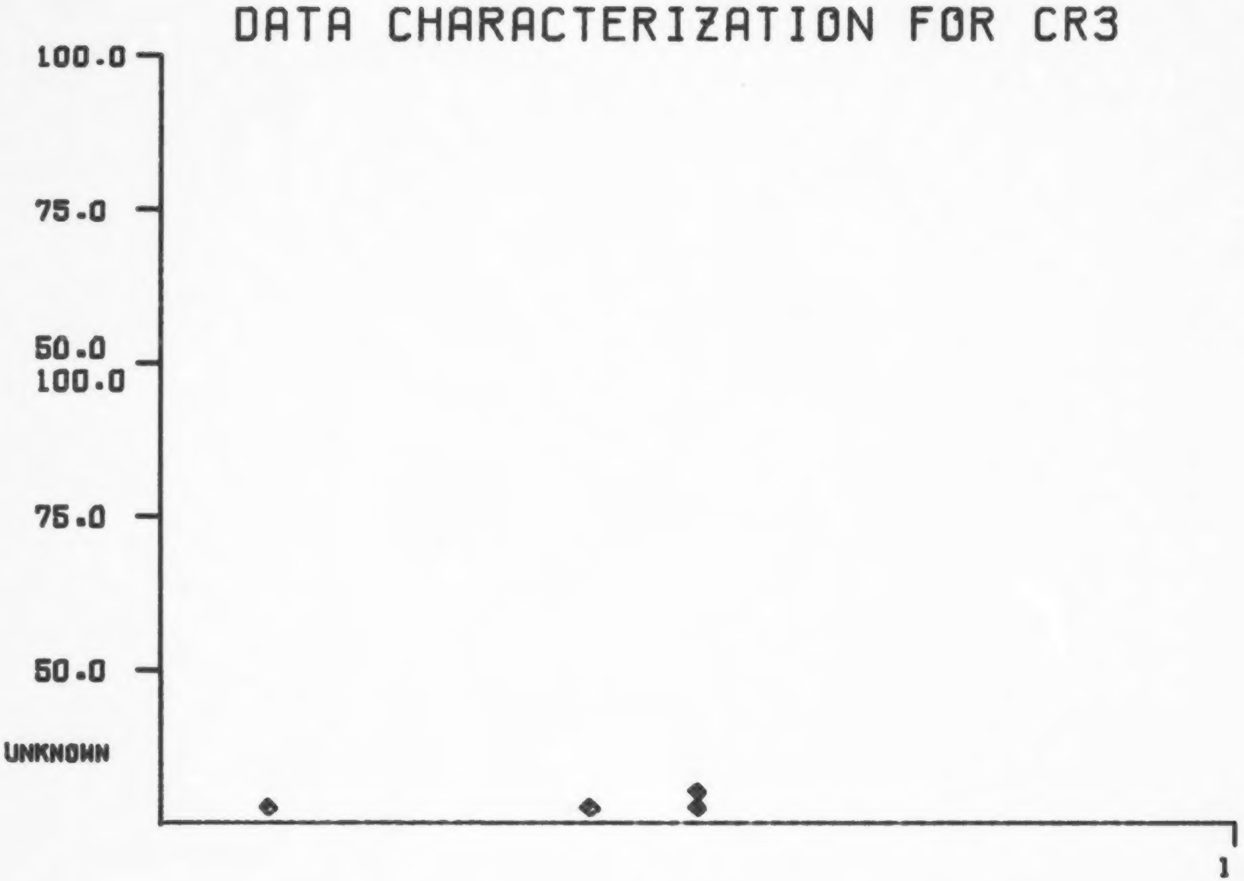
Figure D-39.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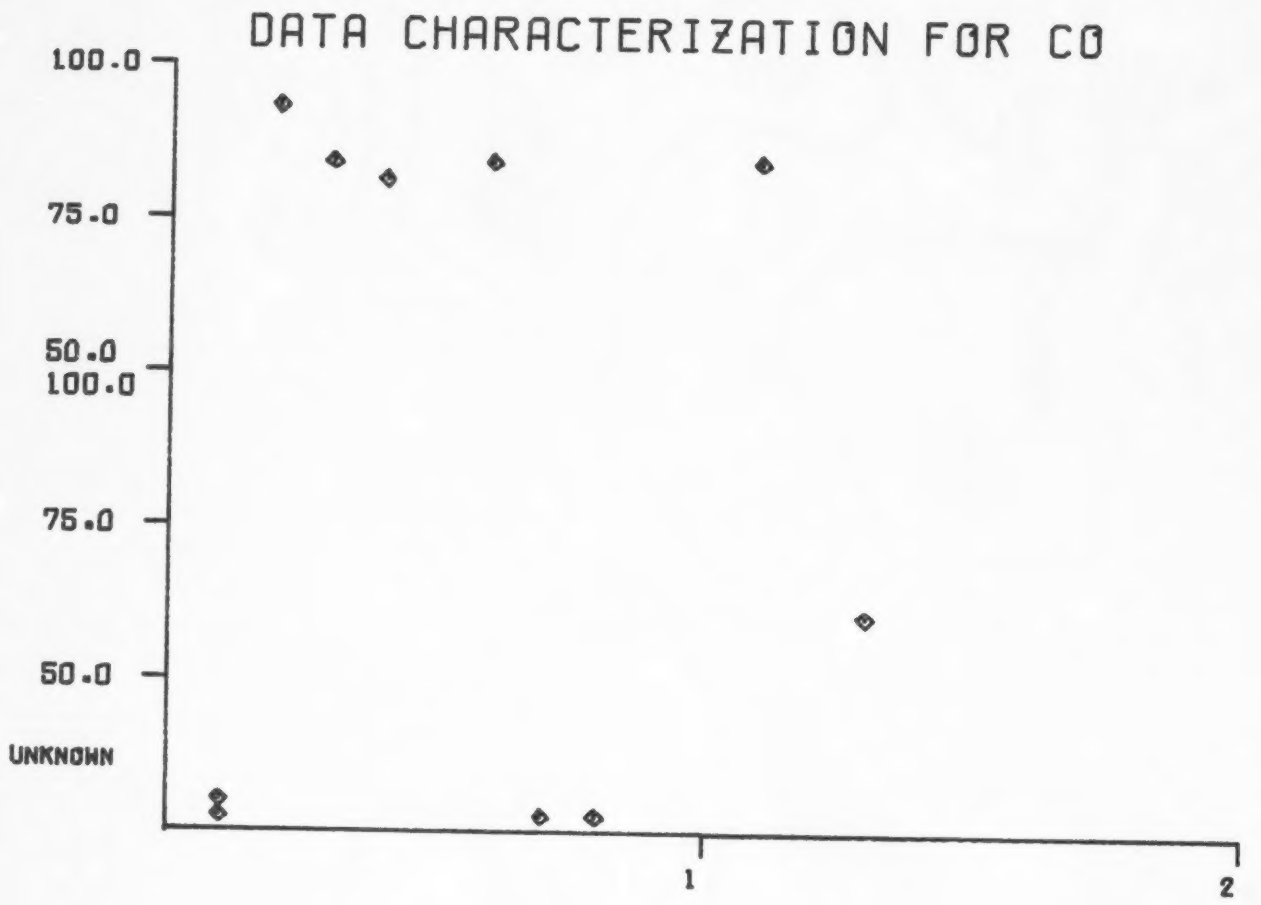
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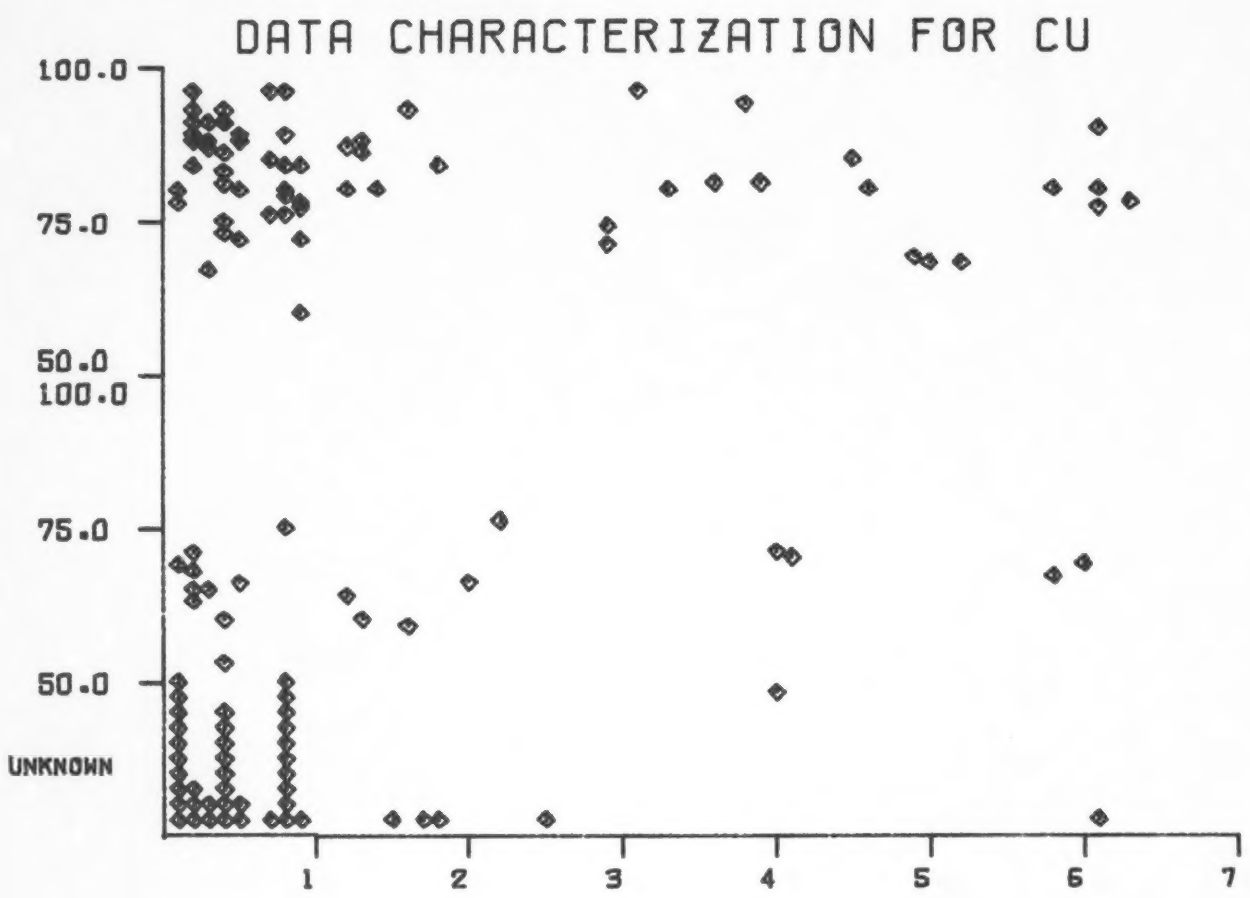
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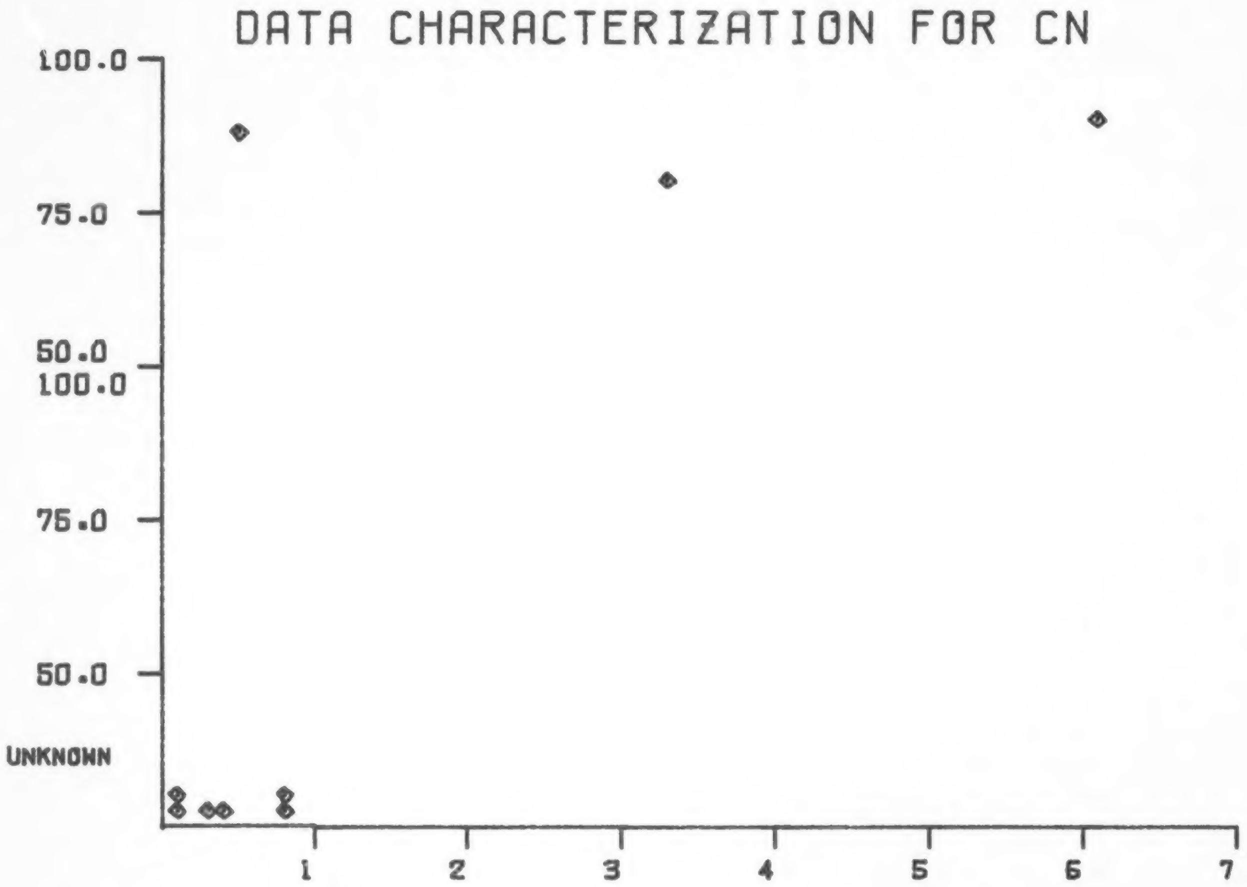
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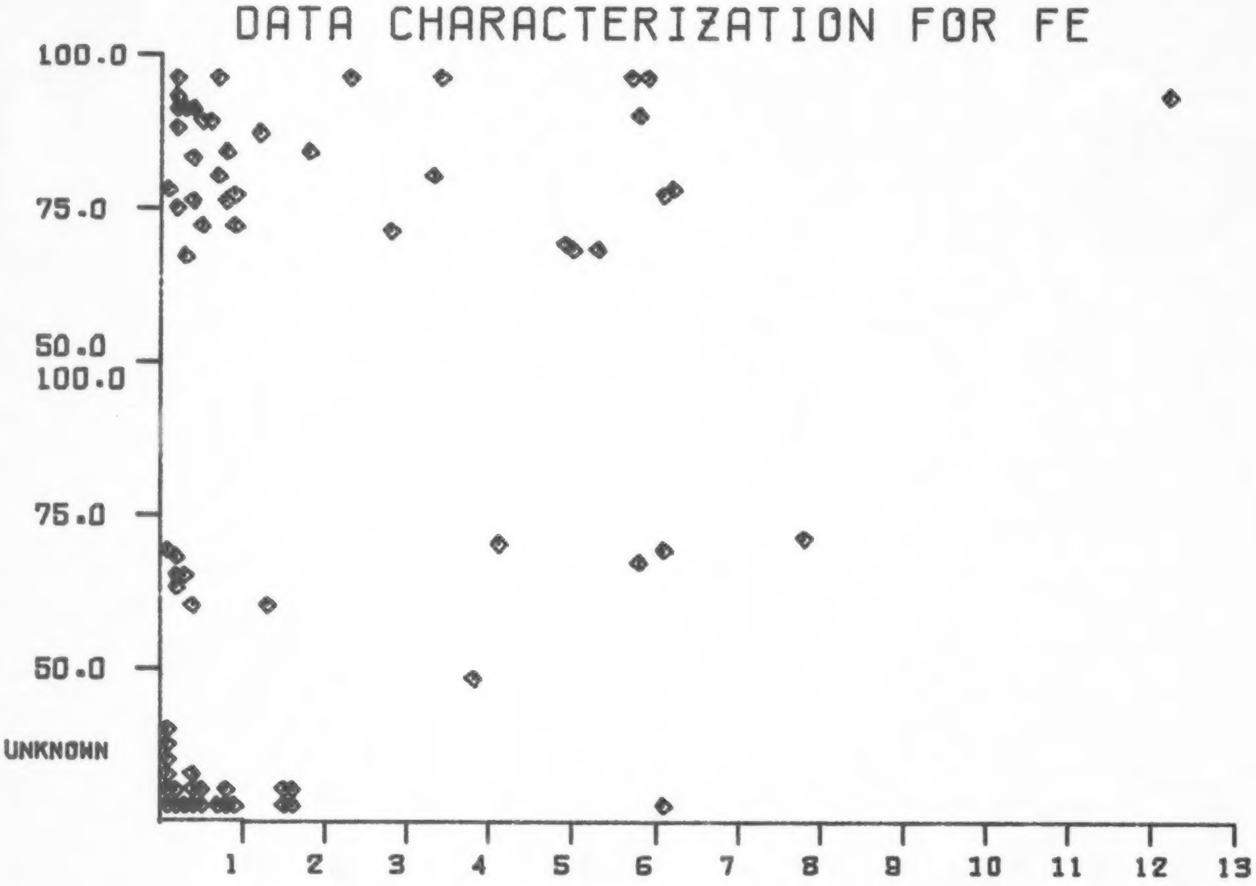
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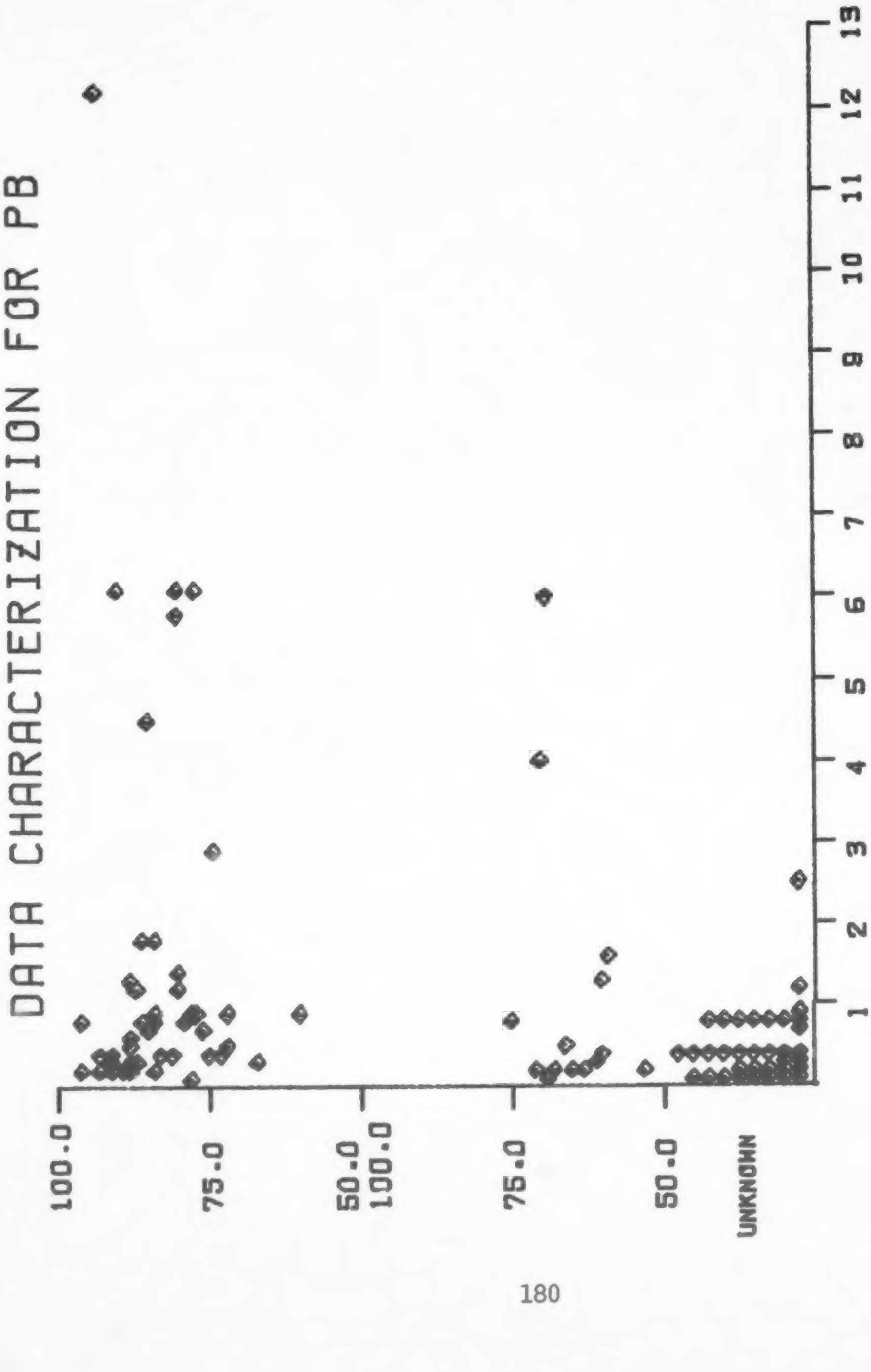
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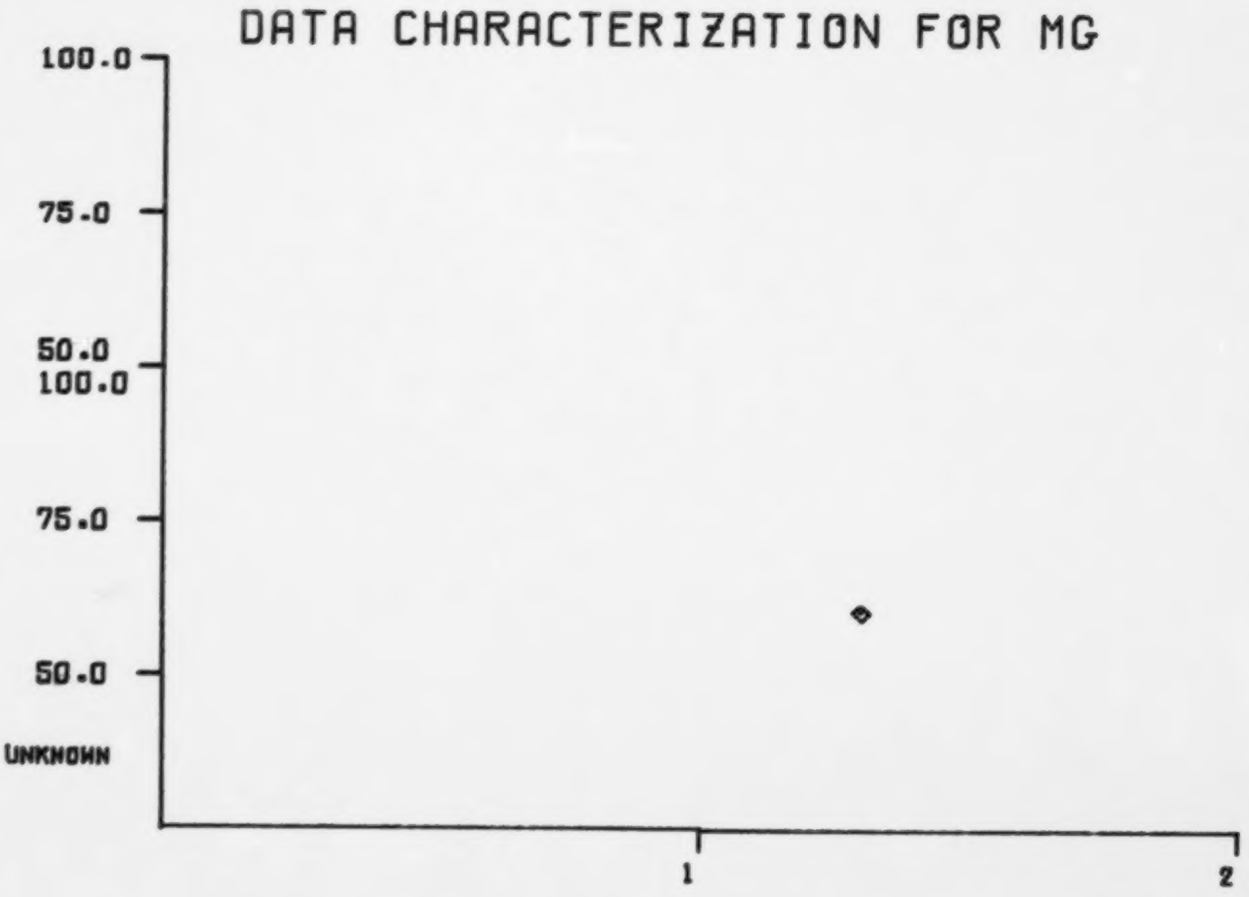
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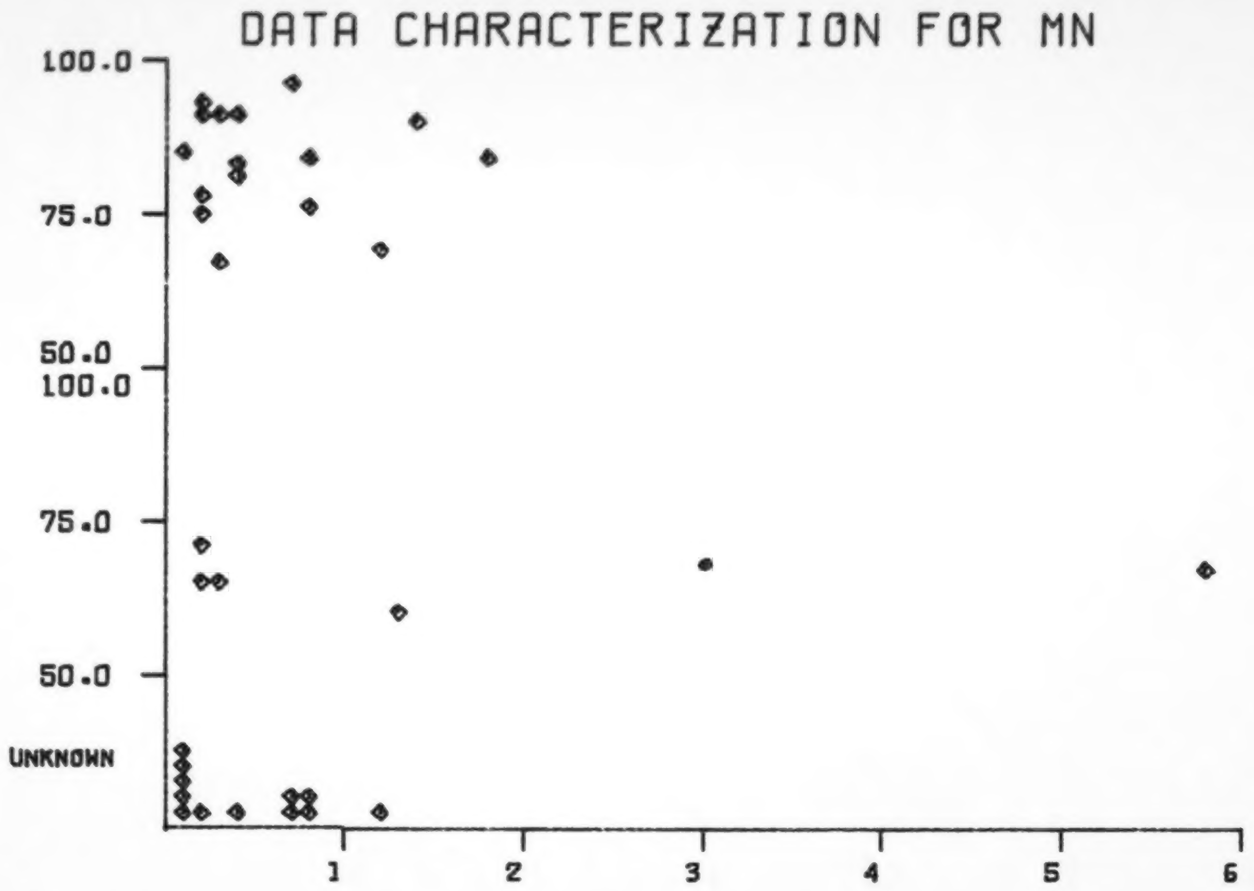
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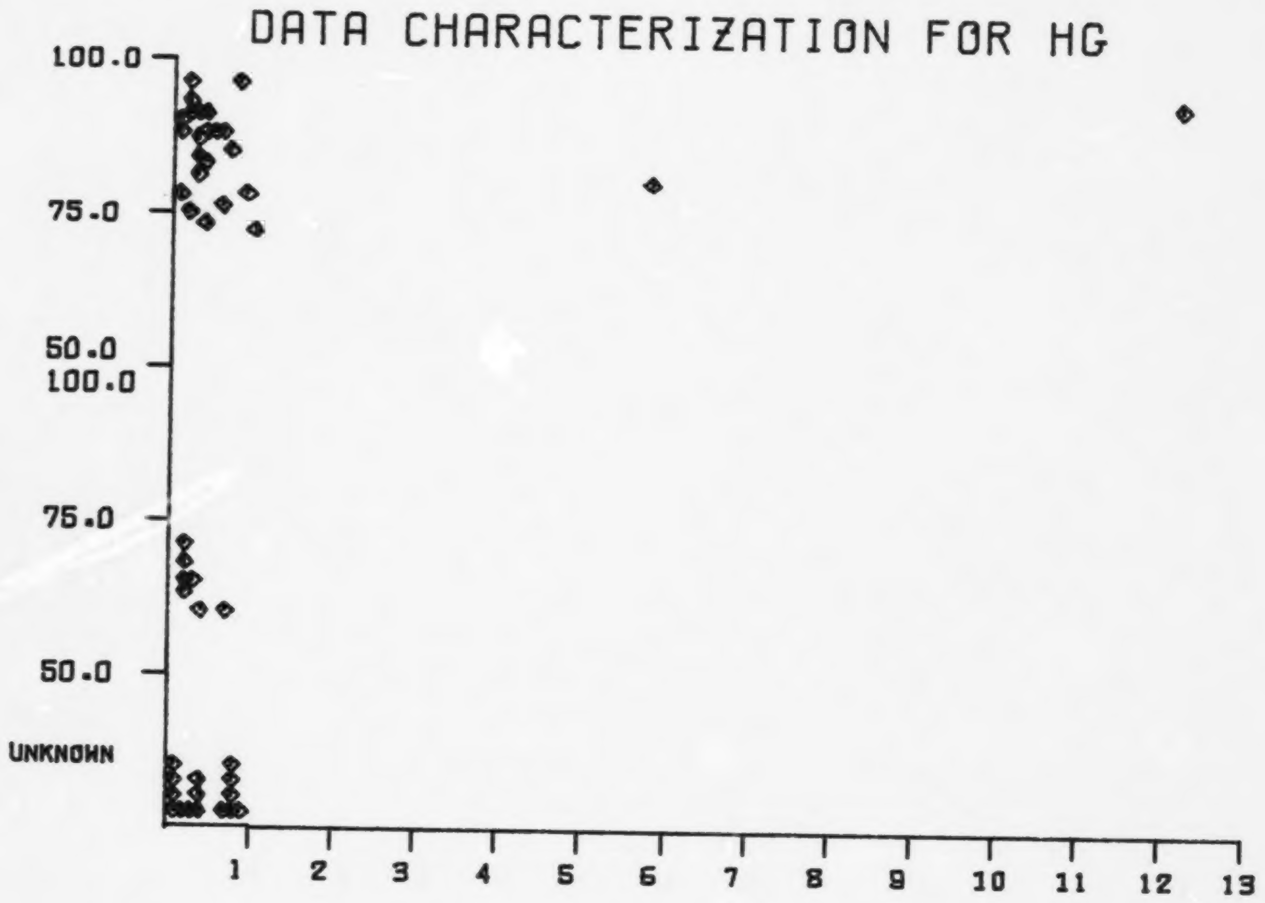
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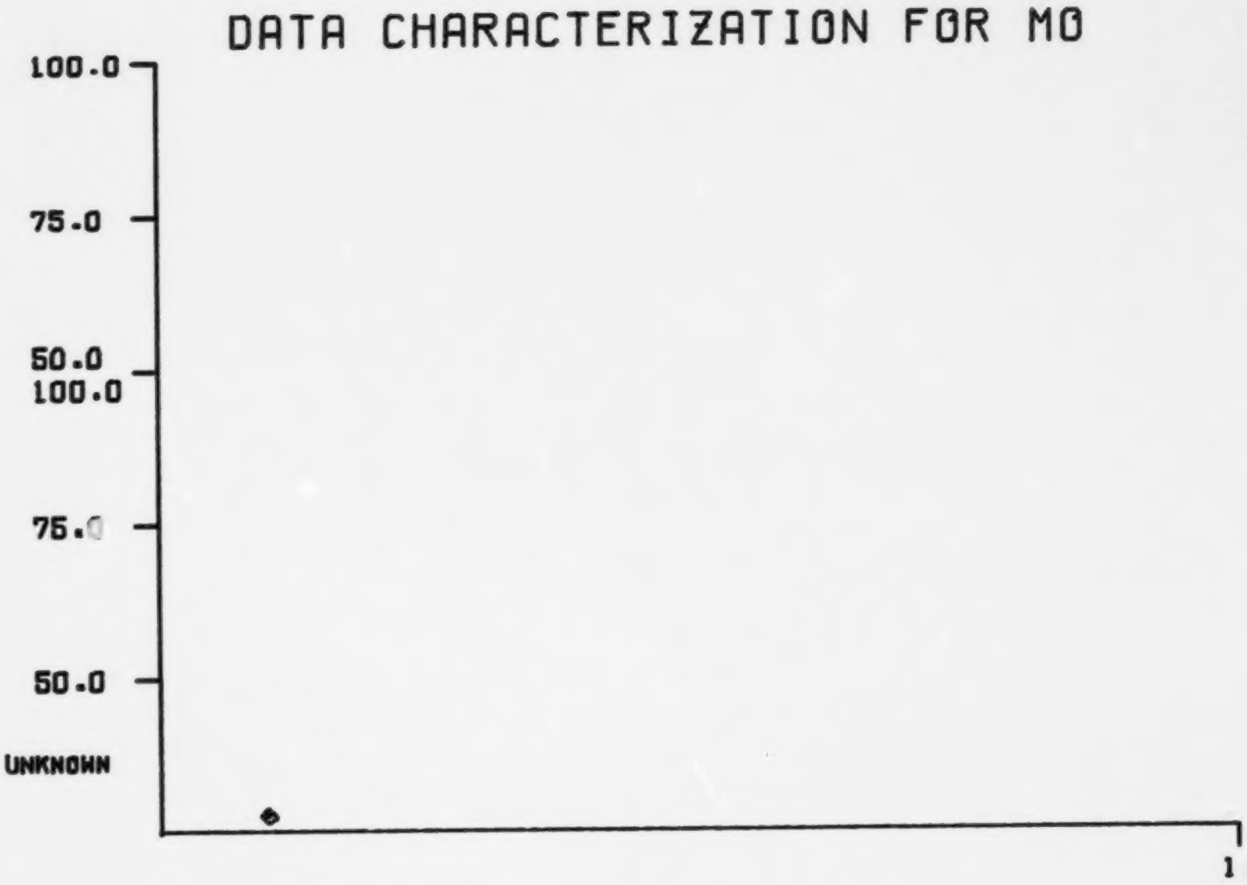
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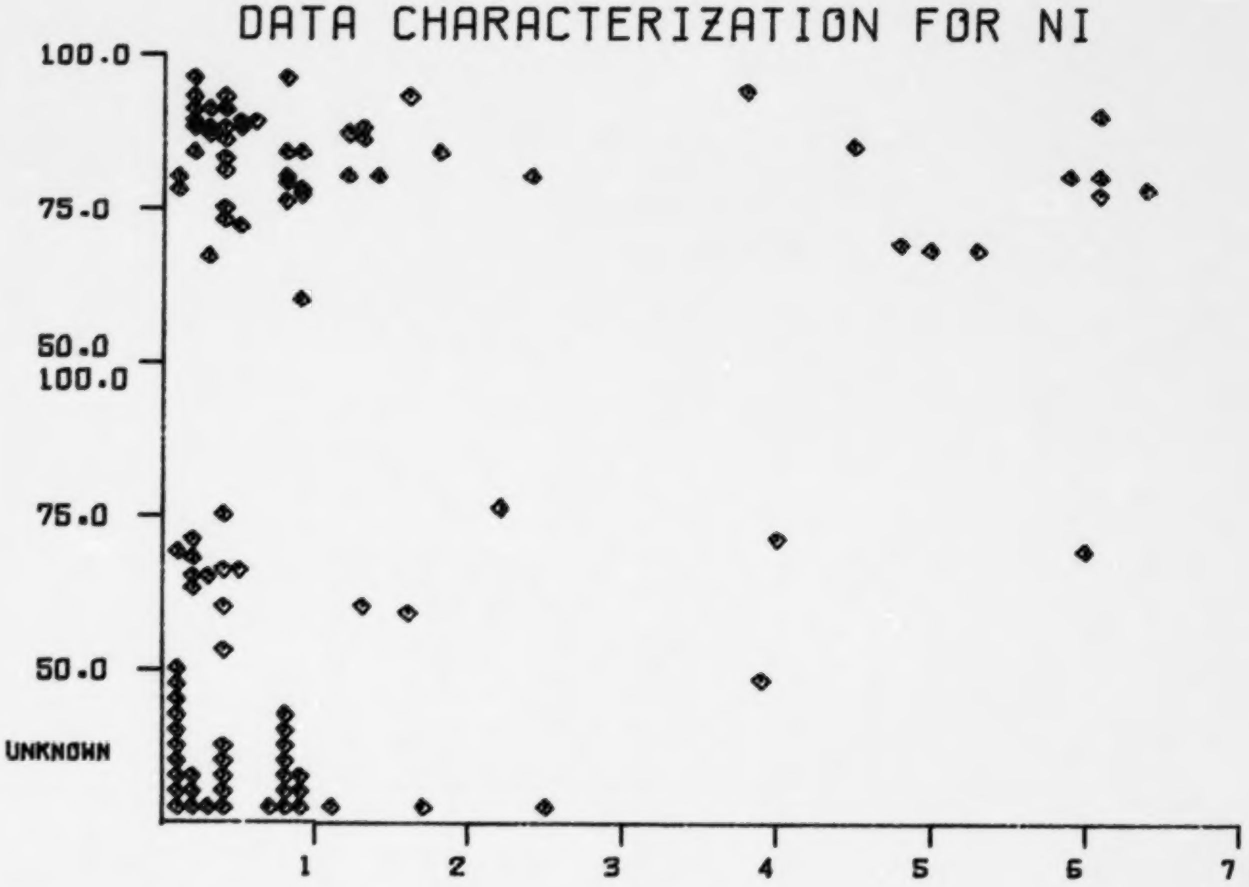
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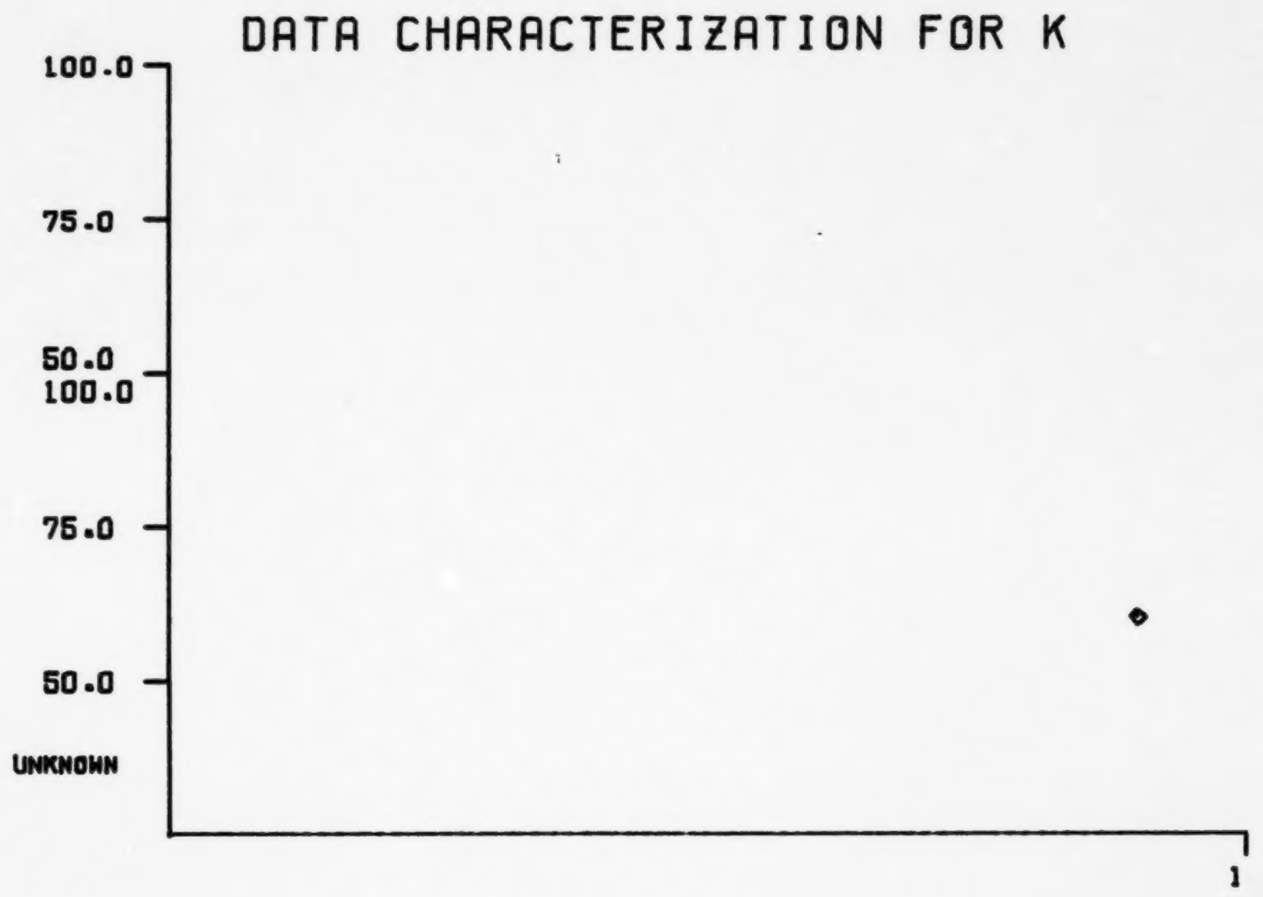
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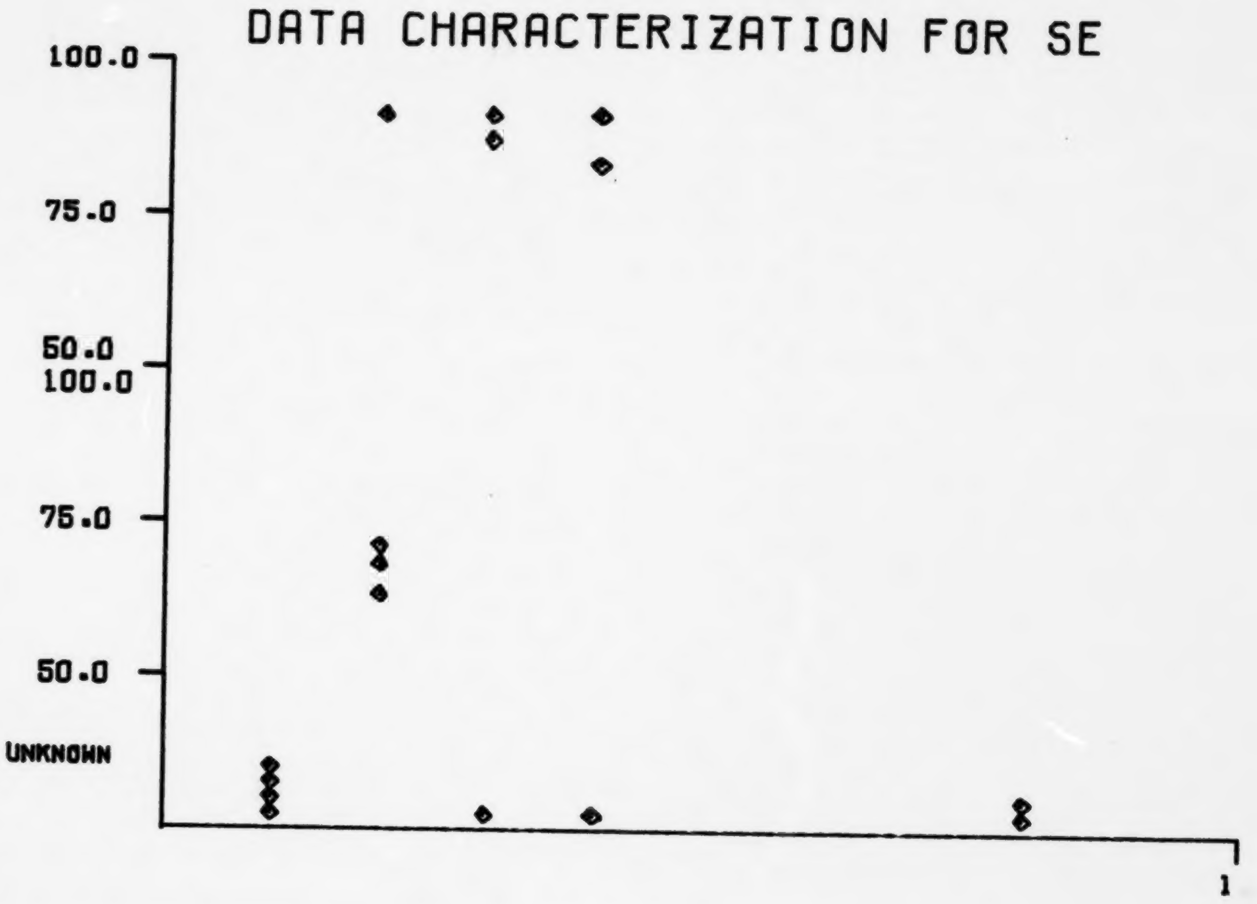
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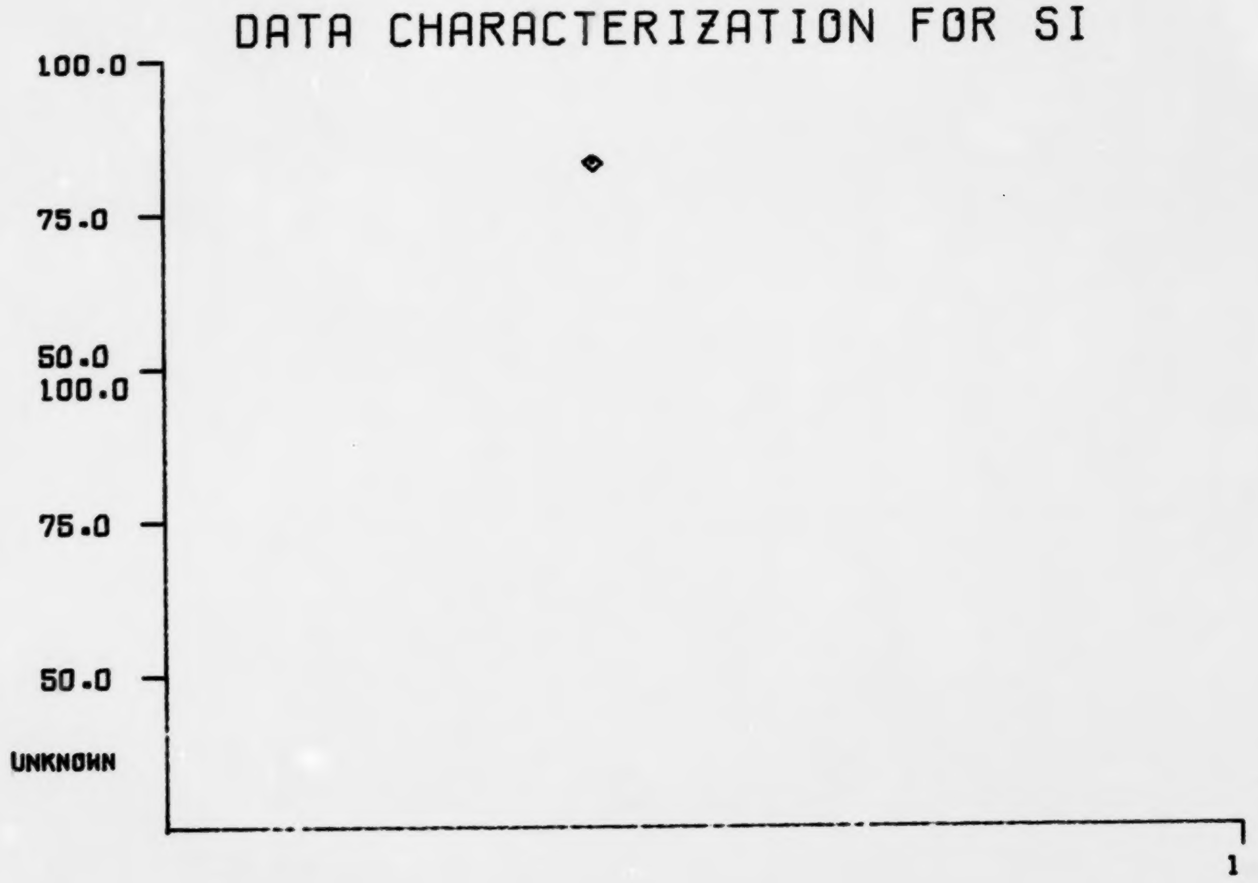
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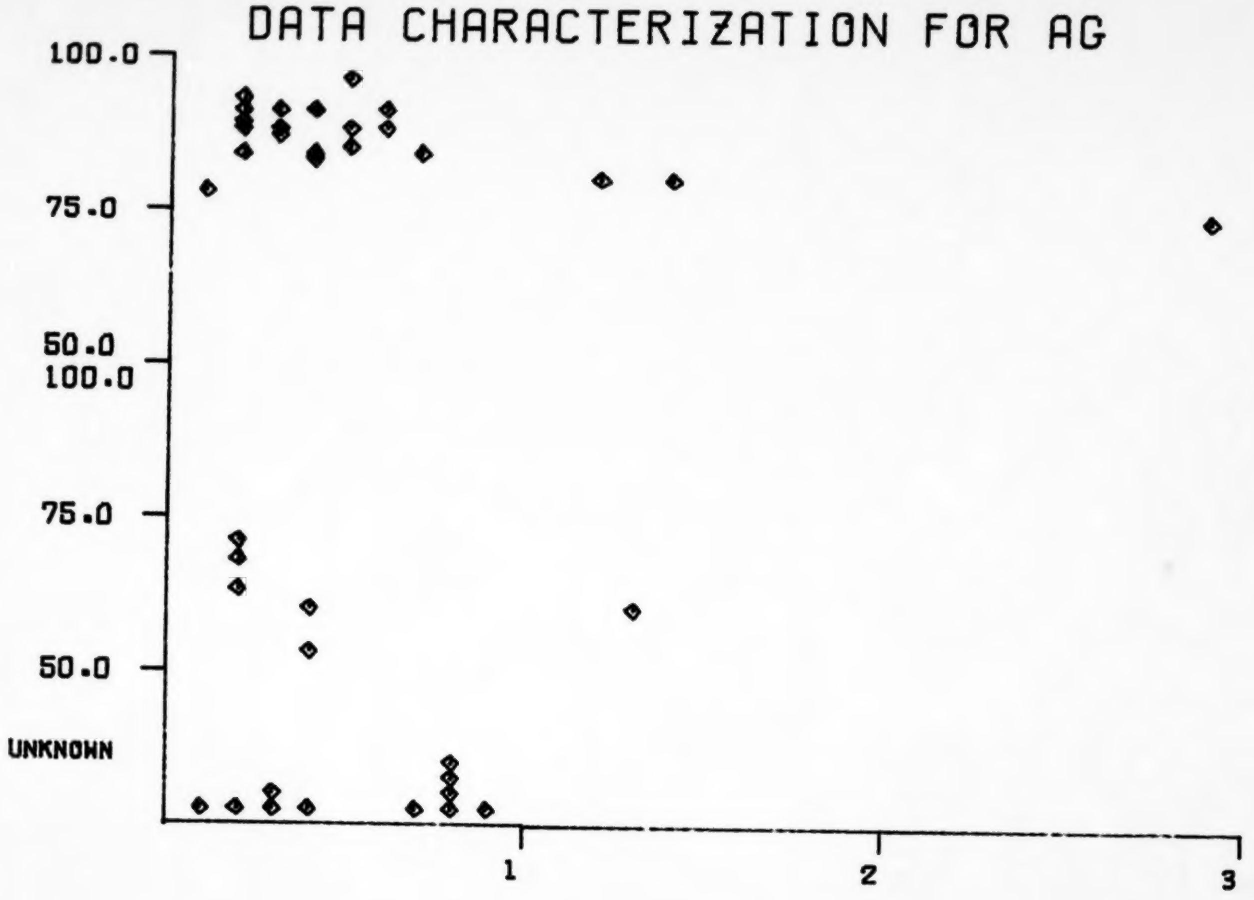
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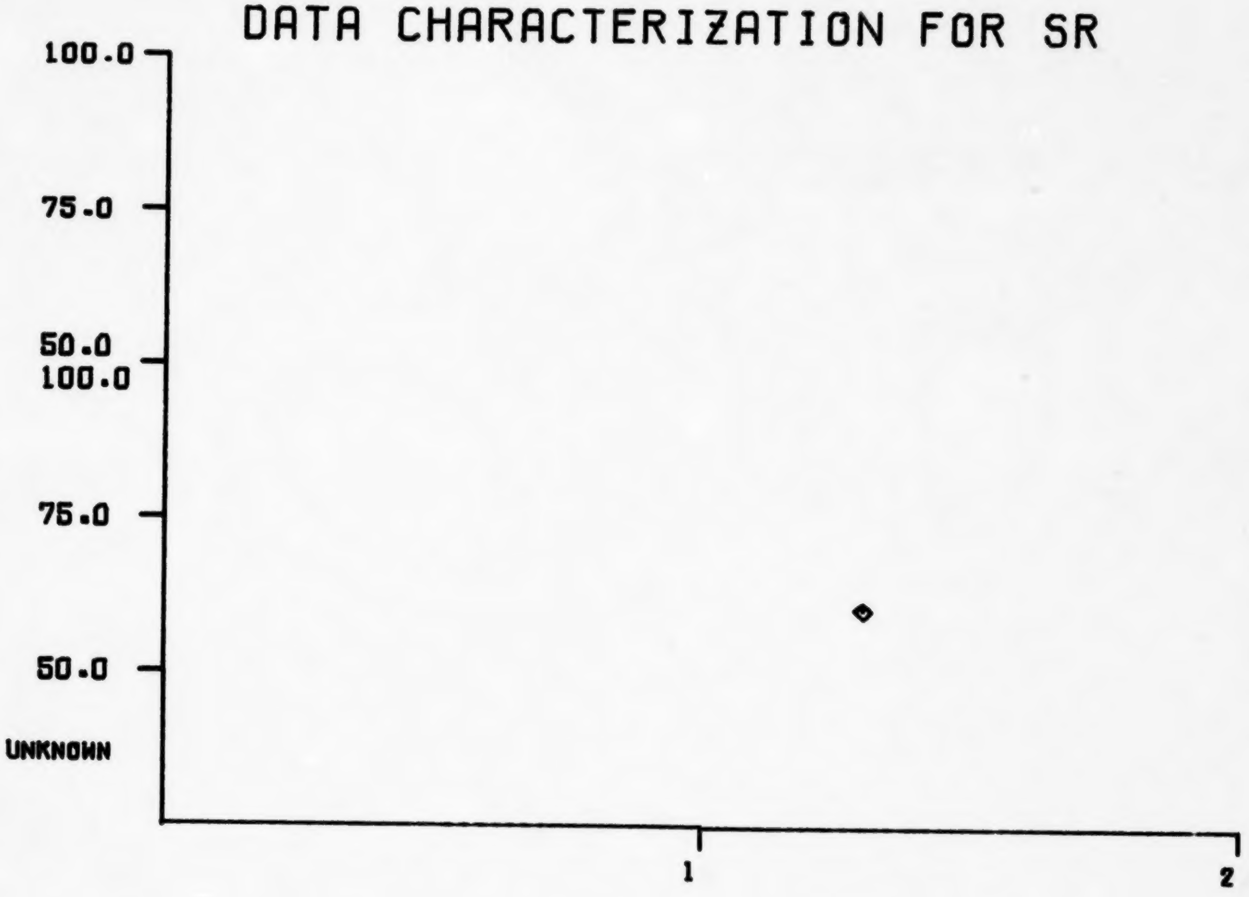
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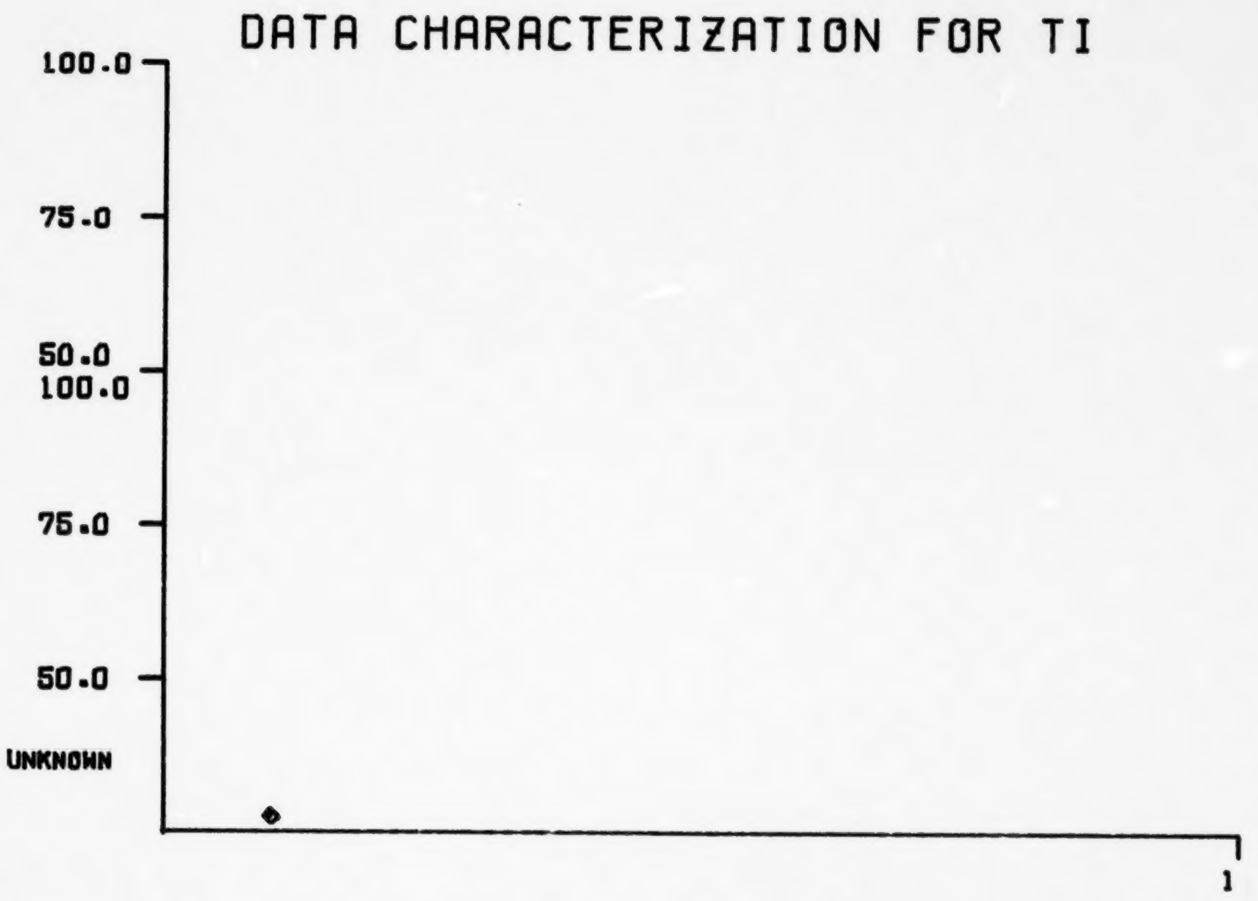
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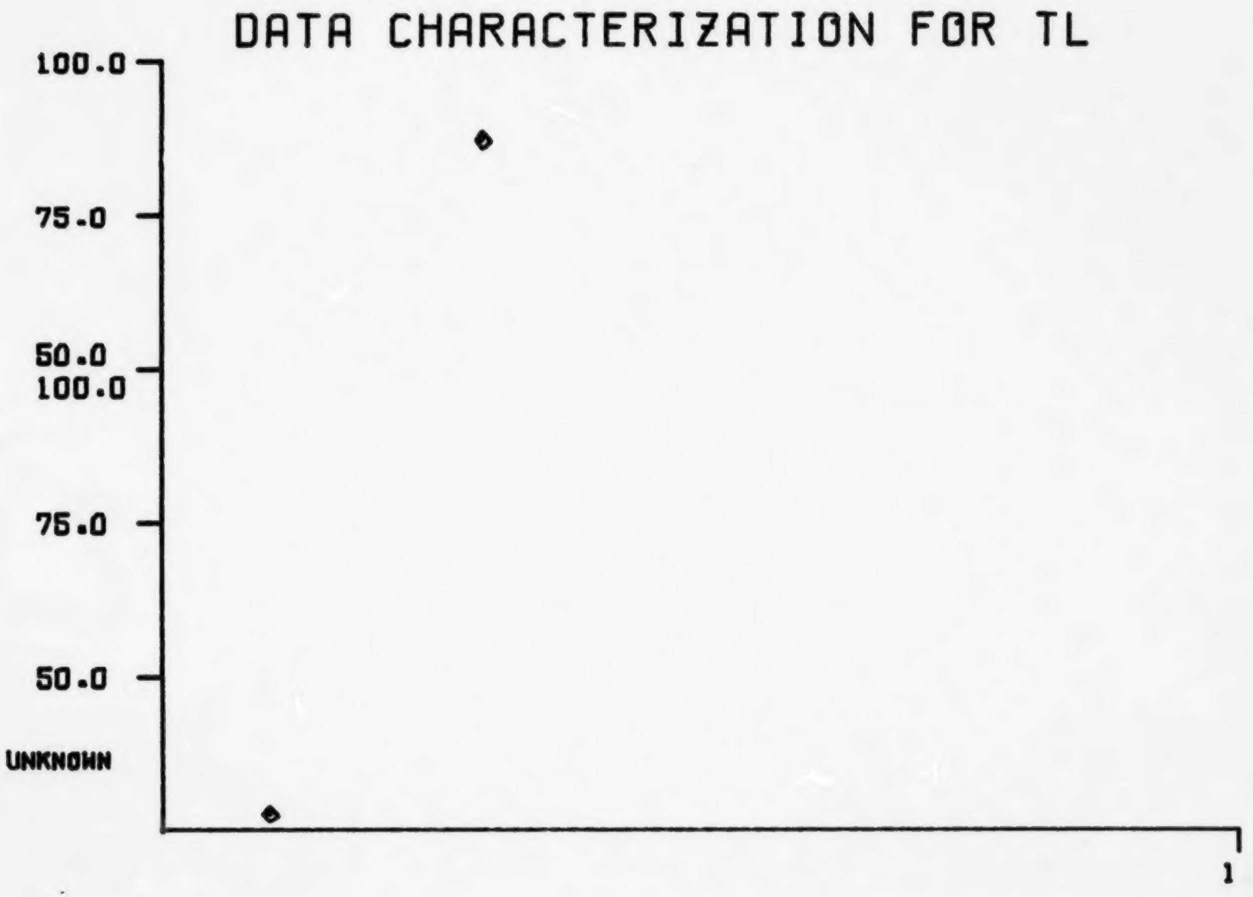
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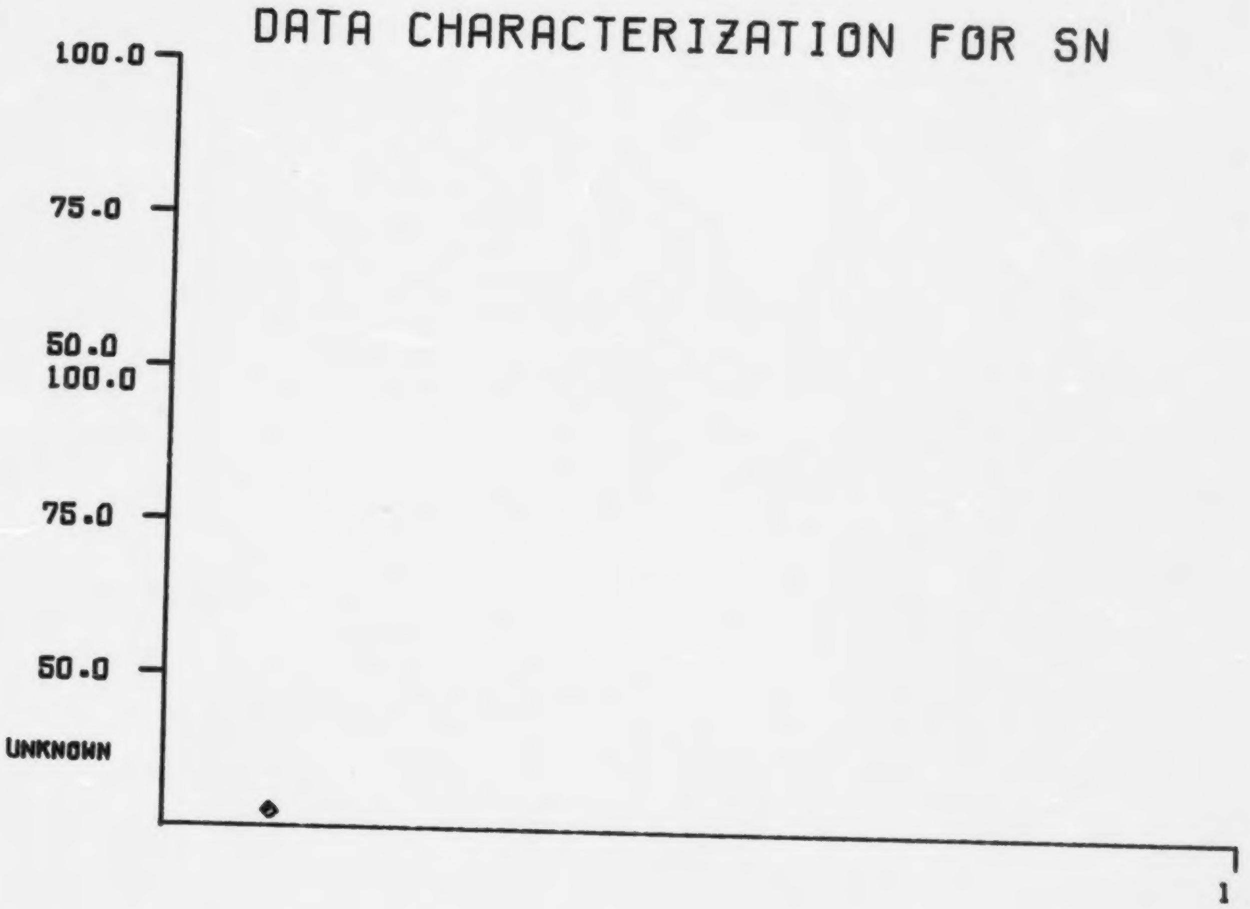
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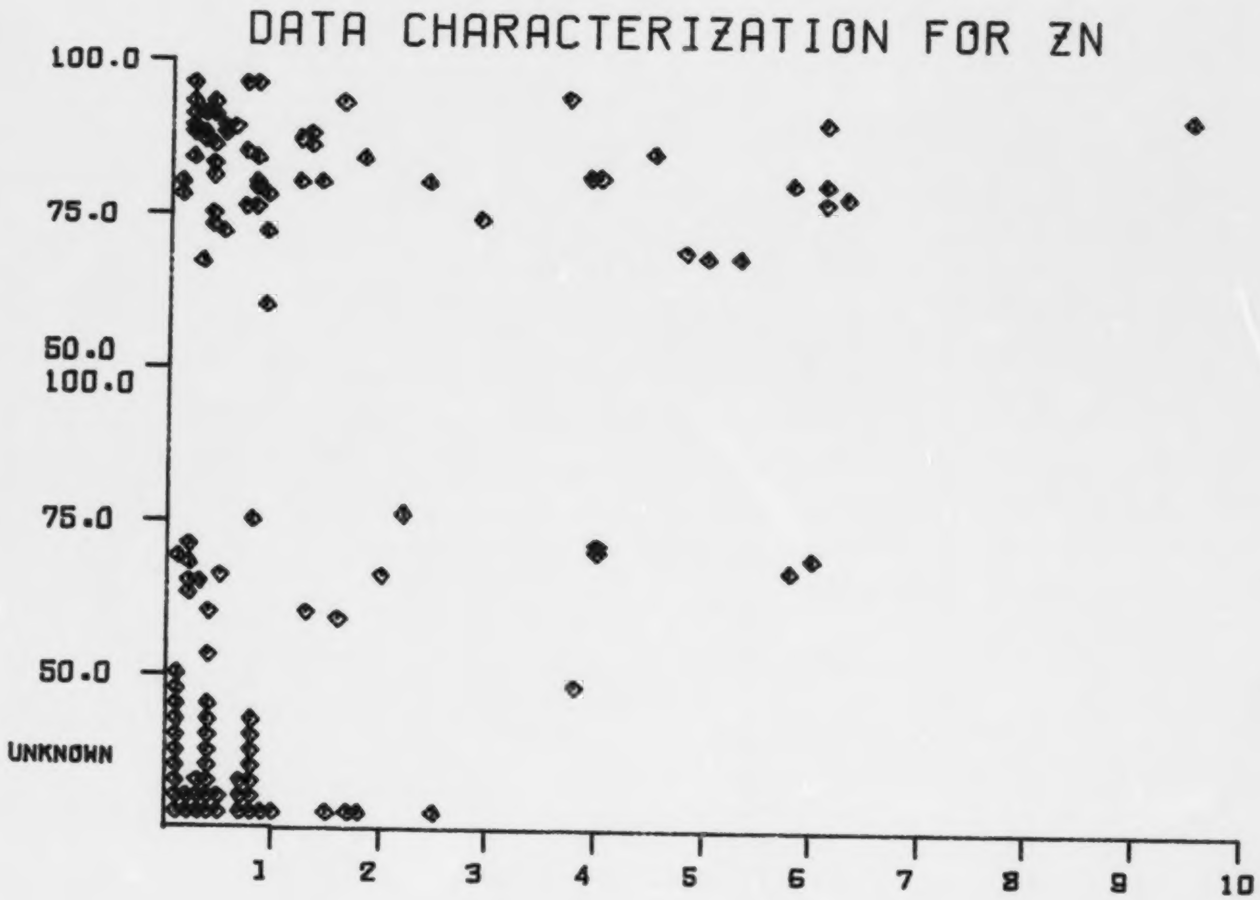
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Figure D-59.

APPENDIX E

PROFILE PLOTS FOR INDIVIDUAL CITIES MEDIAN VALUES VERSUS DATA BASE MEDIAN (Al, Cr, Co, Cu, Fe, Pb, Mn, Hg, Ni, Zn)

Plots 2-36 represent multiple plant cities (Plot 30 is Figure 23.

Plots 37-47 represent single plant cities (each line is for a different city).

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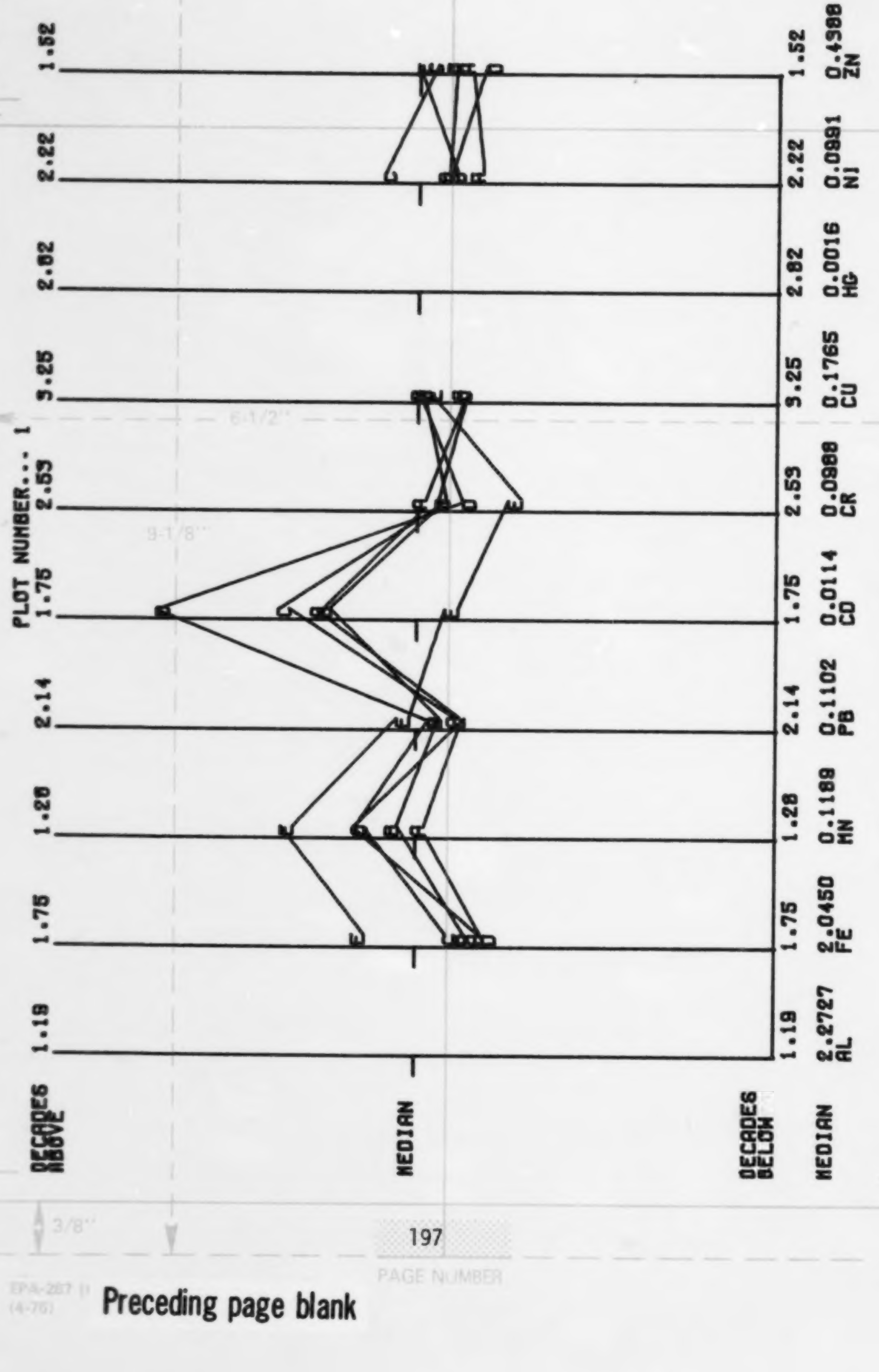

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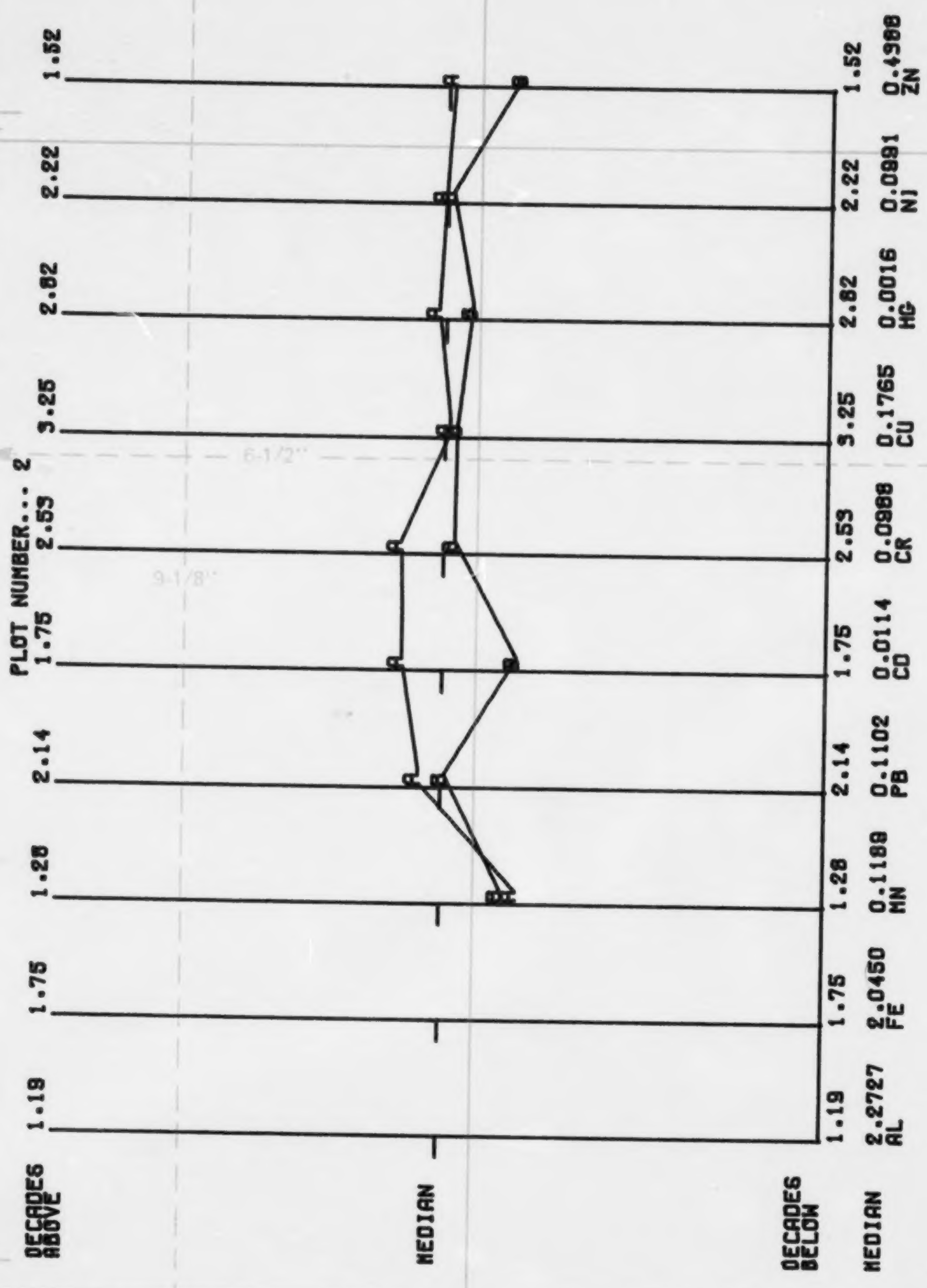

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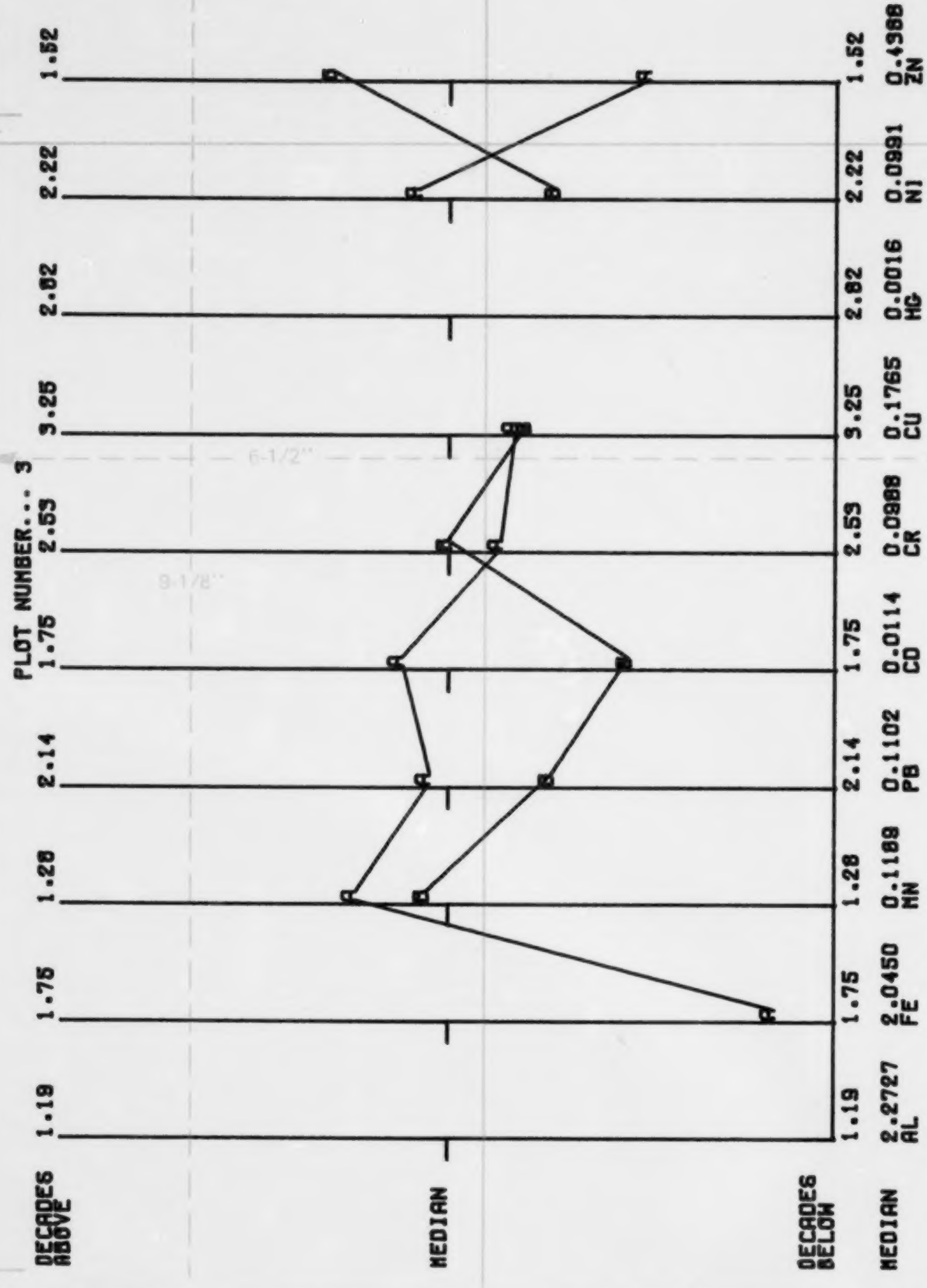

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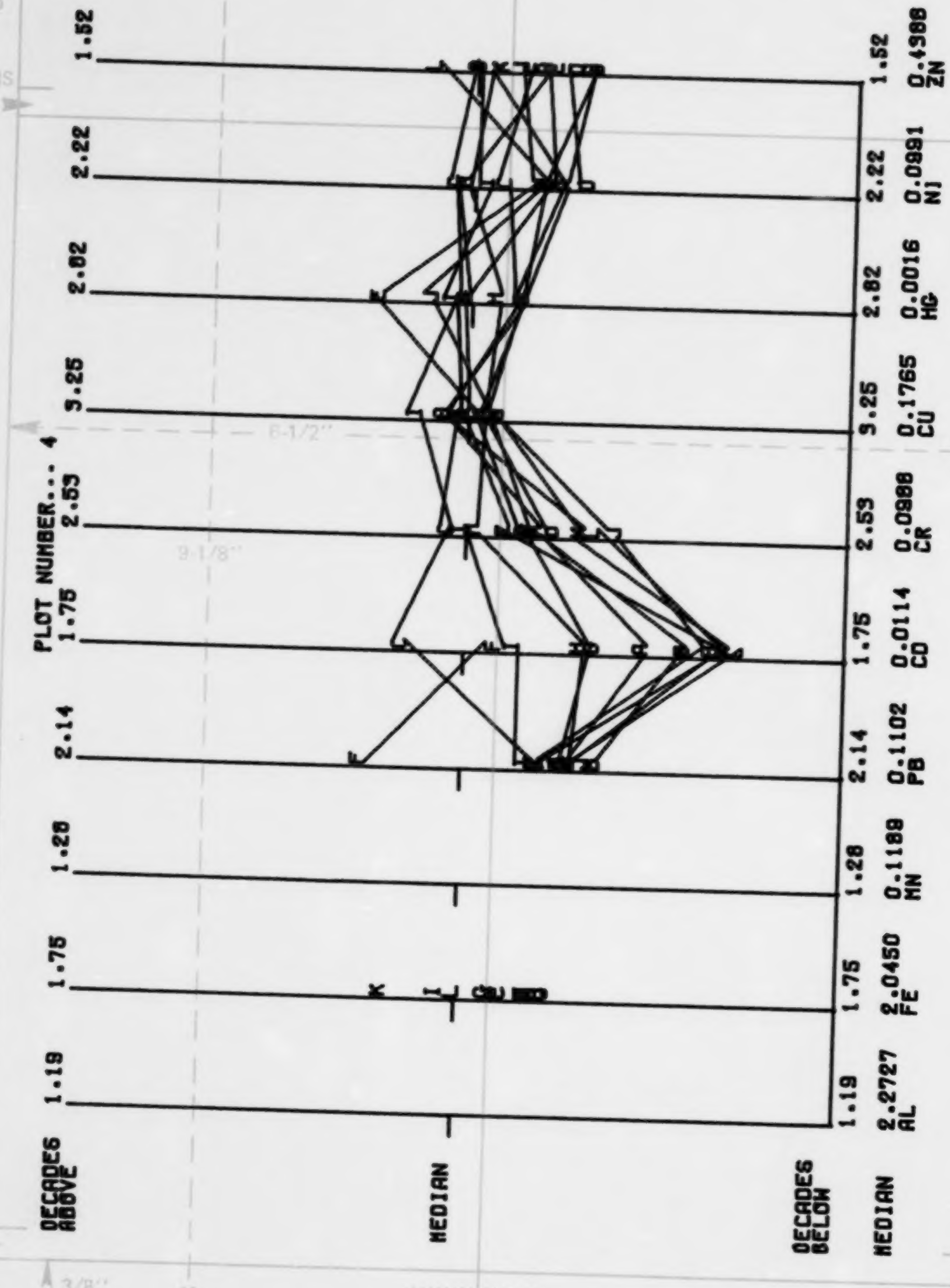

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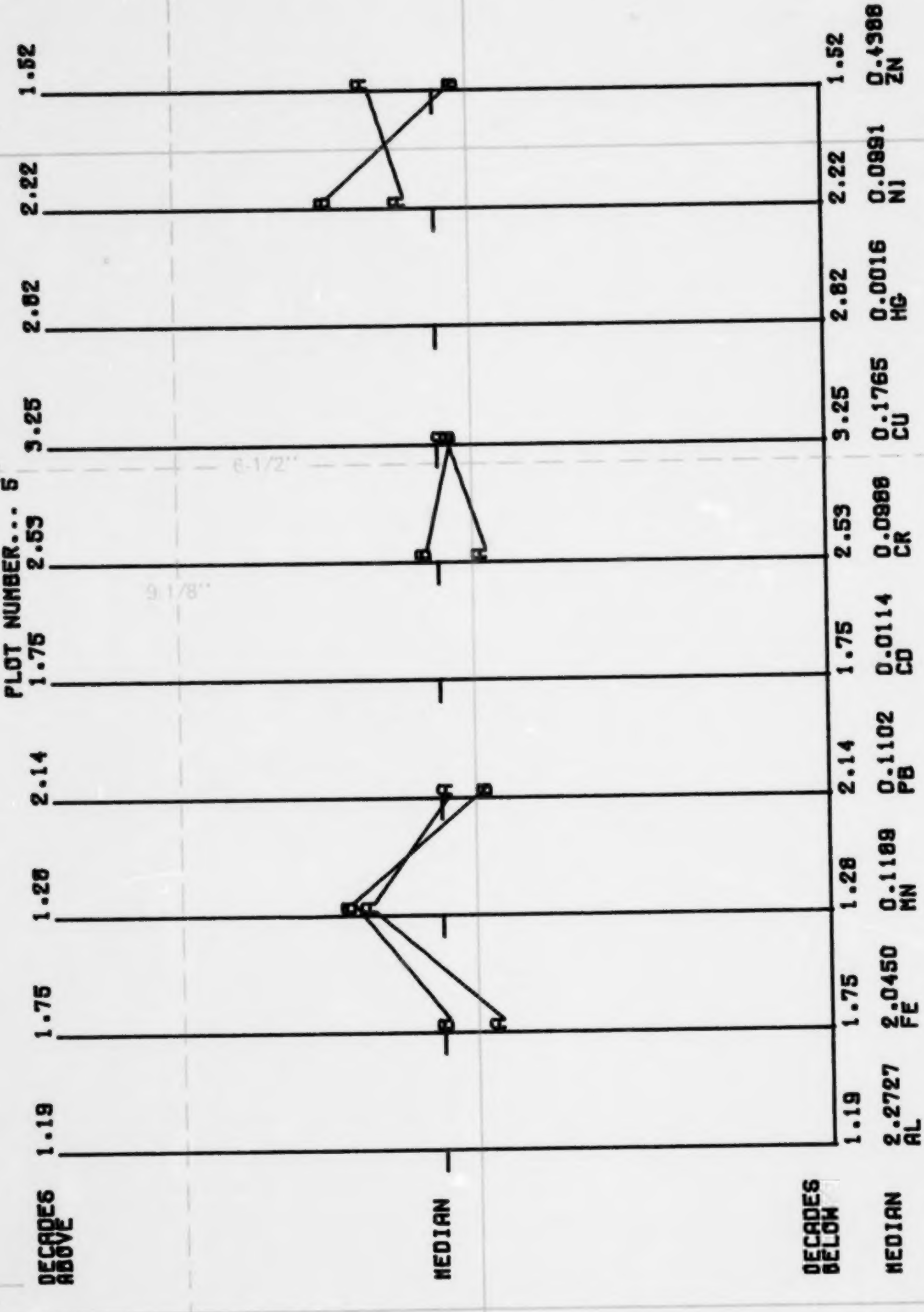

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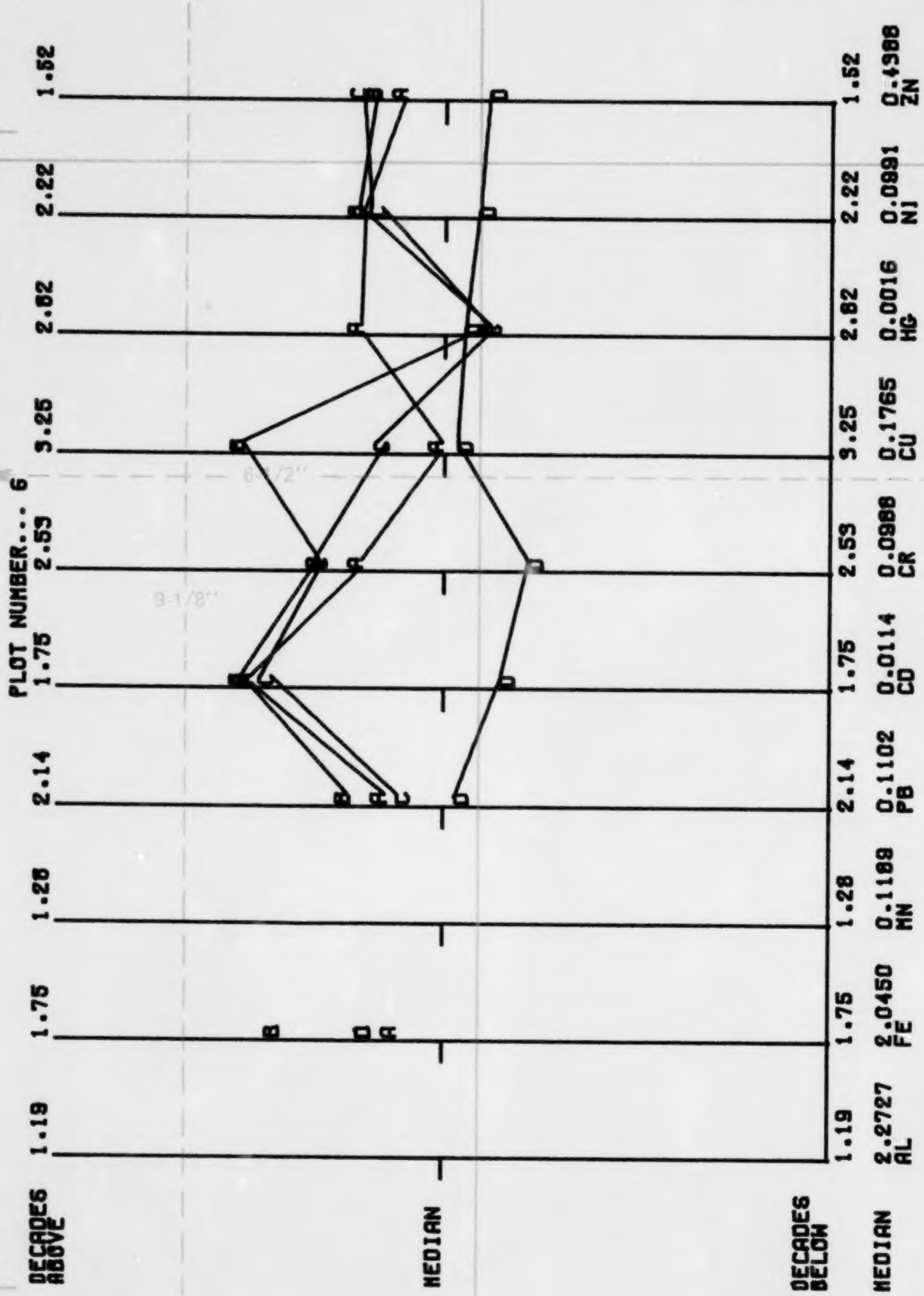

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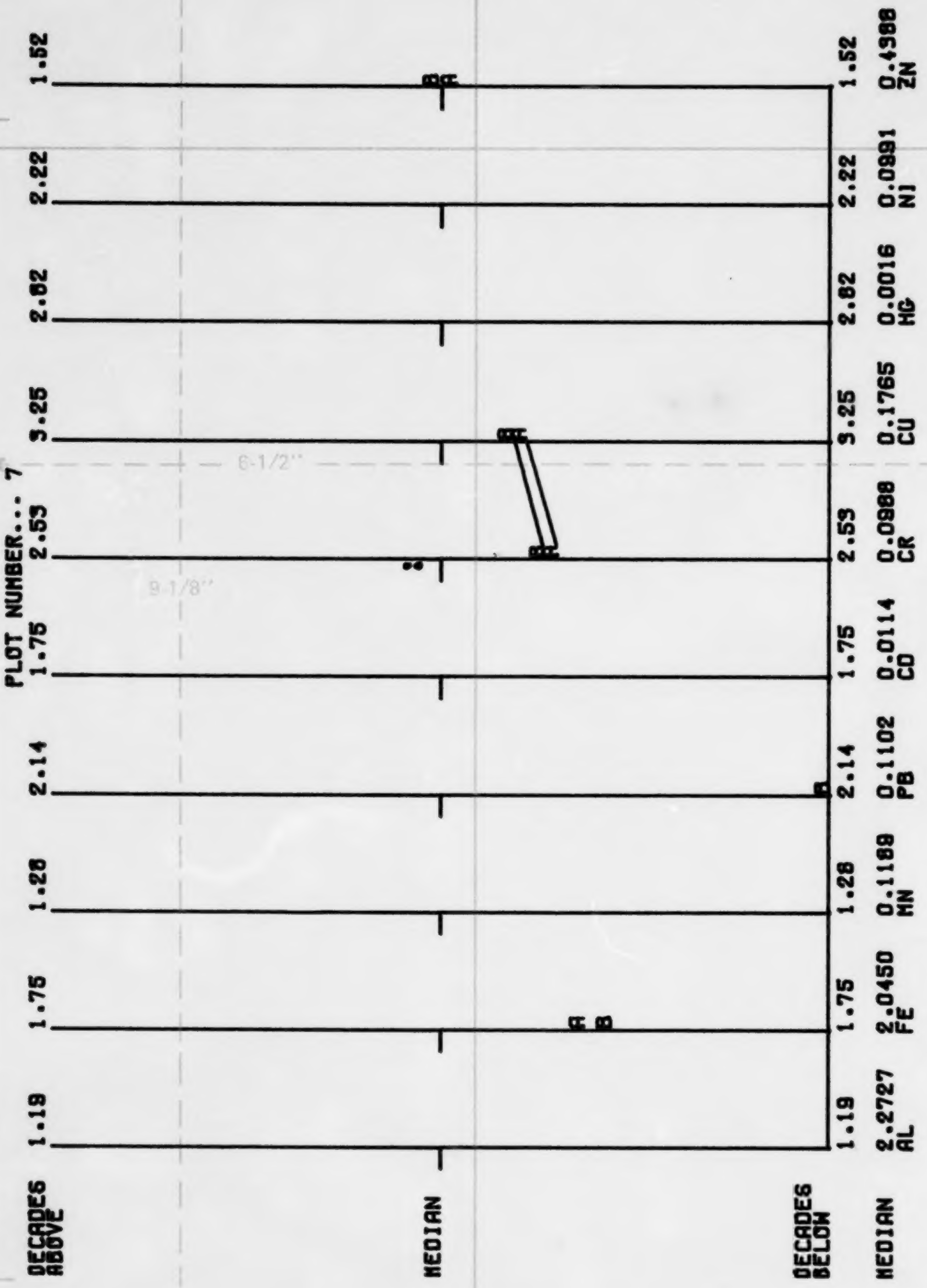

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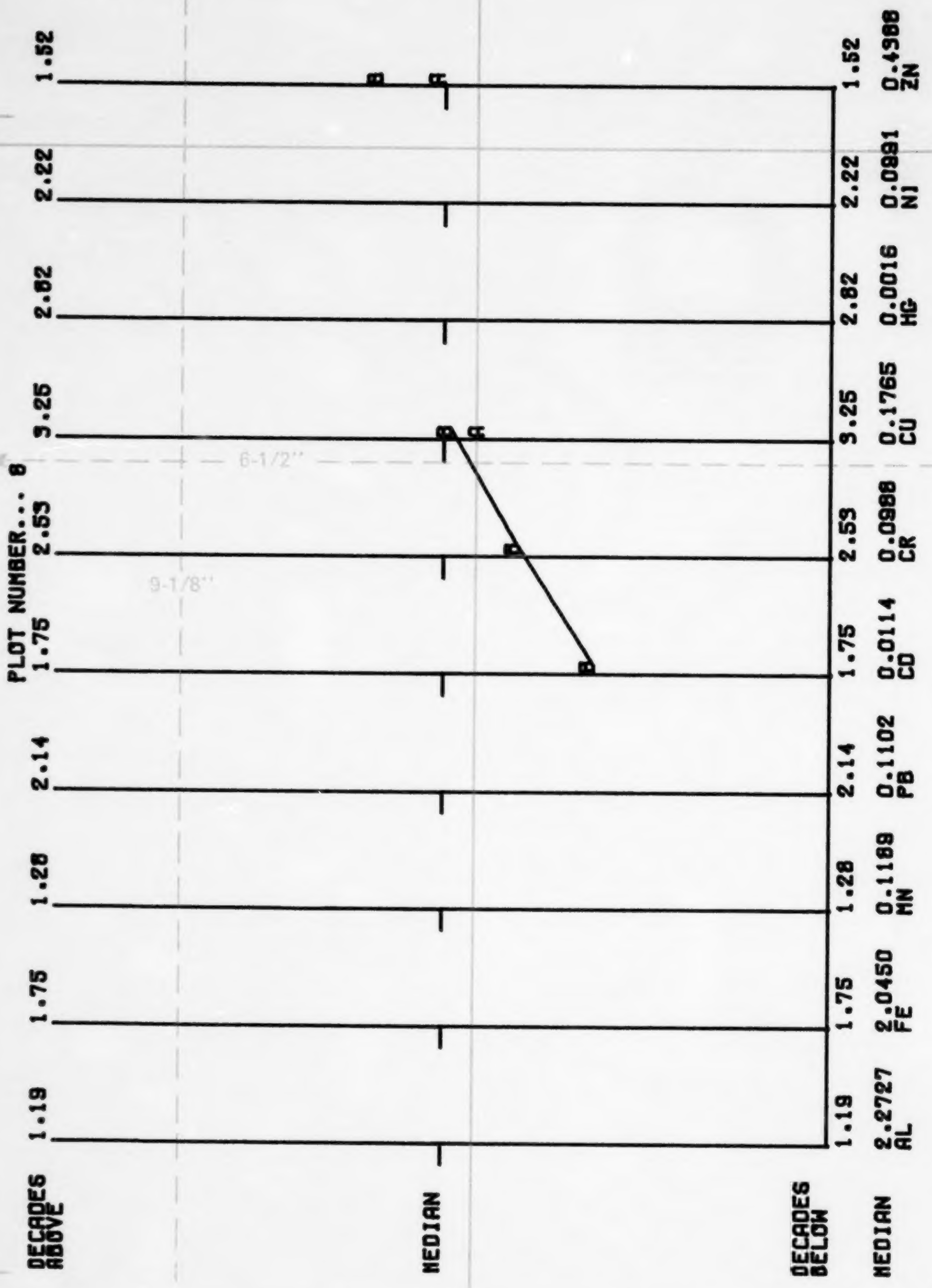

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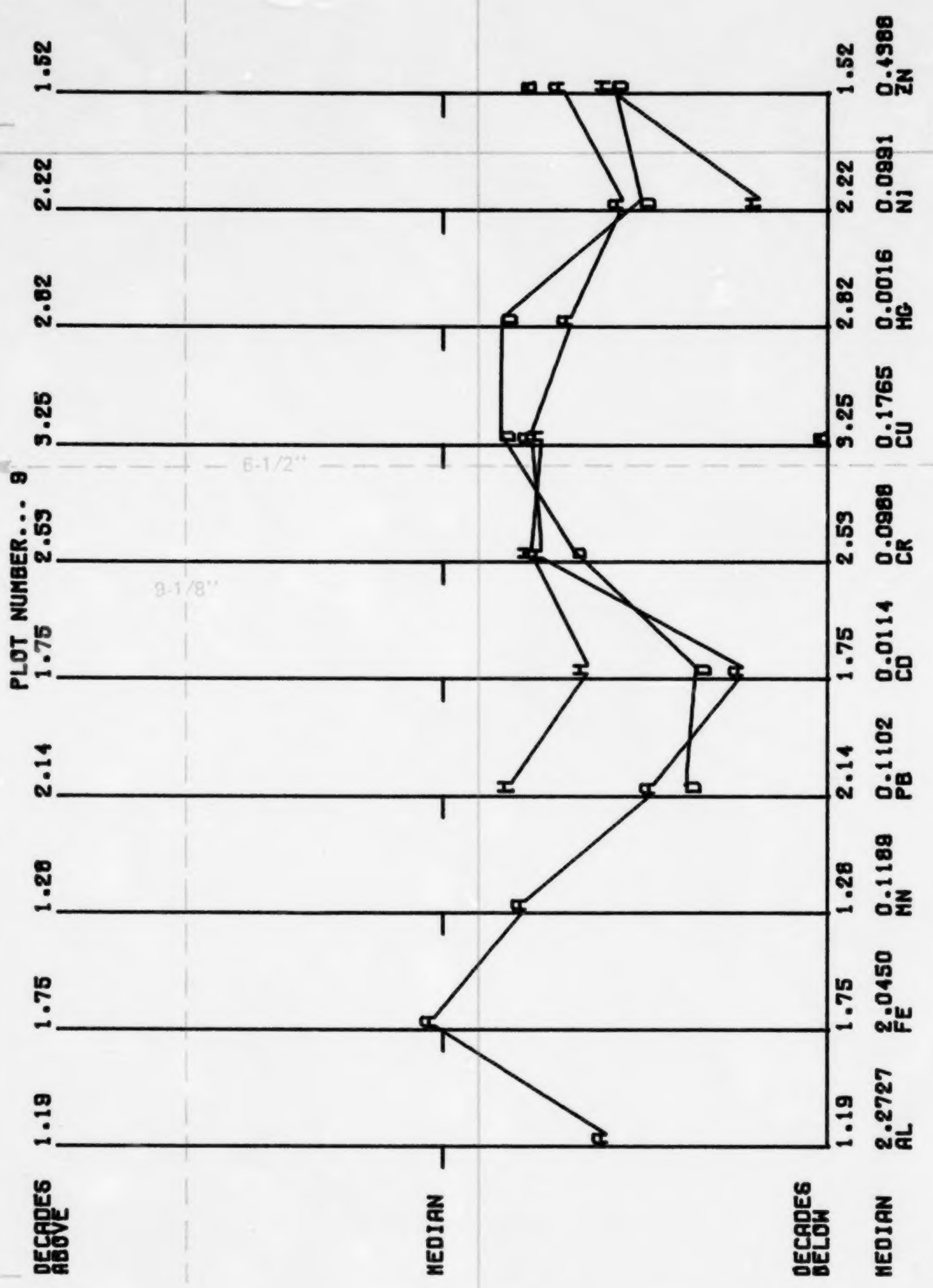

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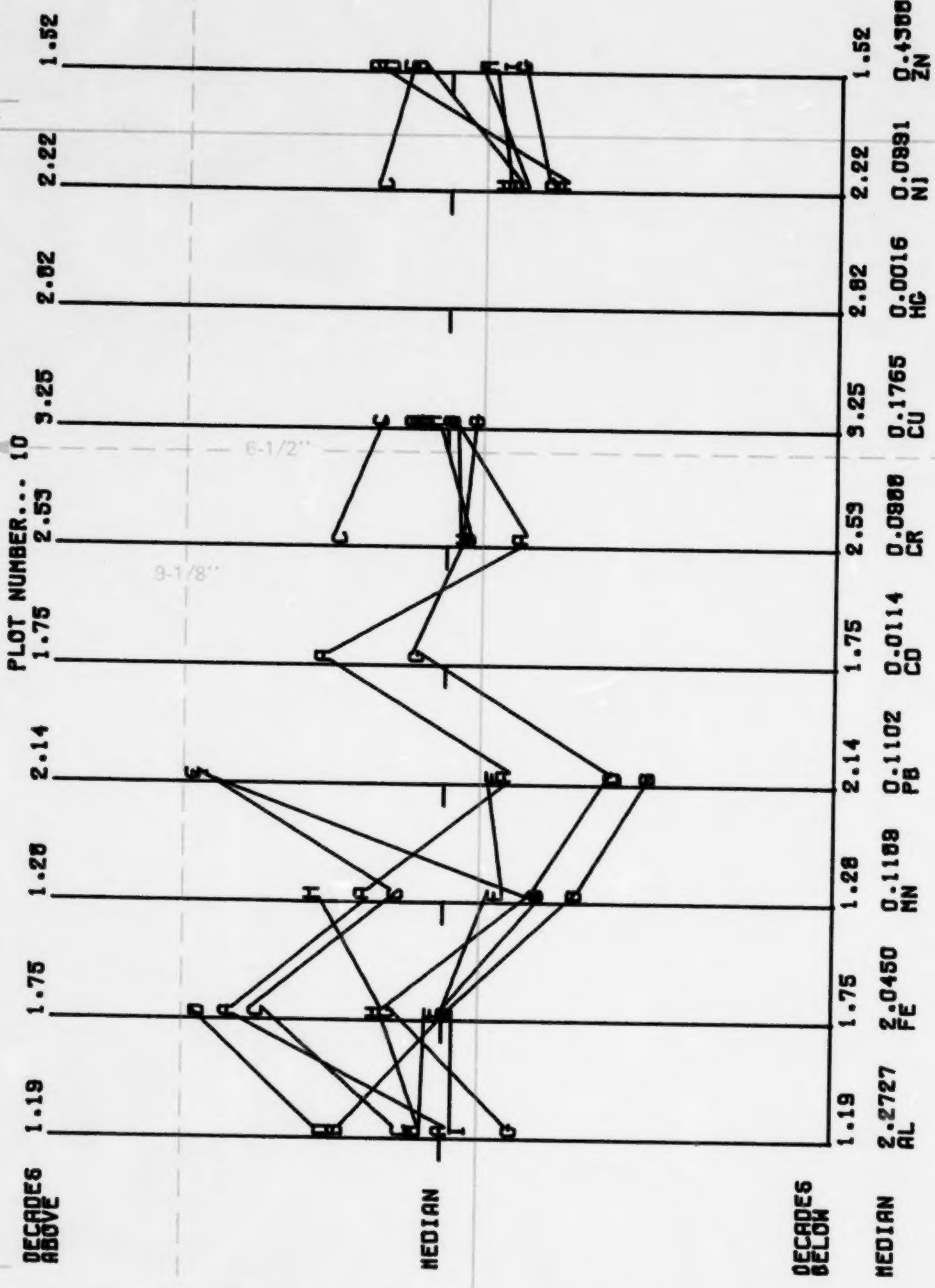

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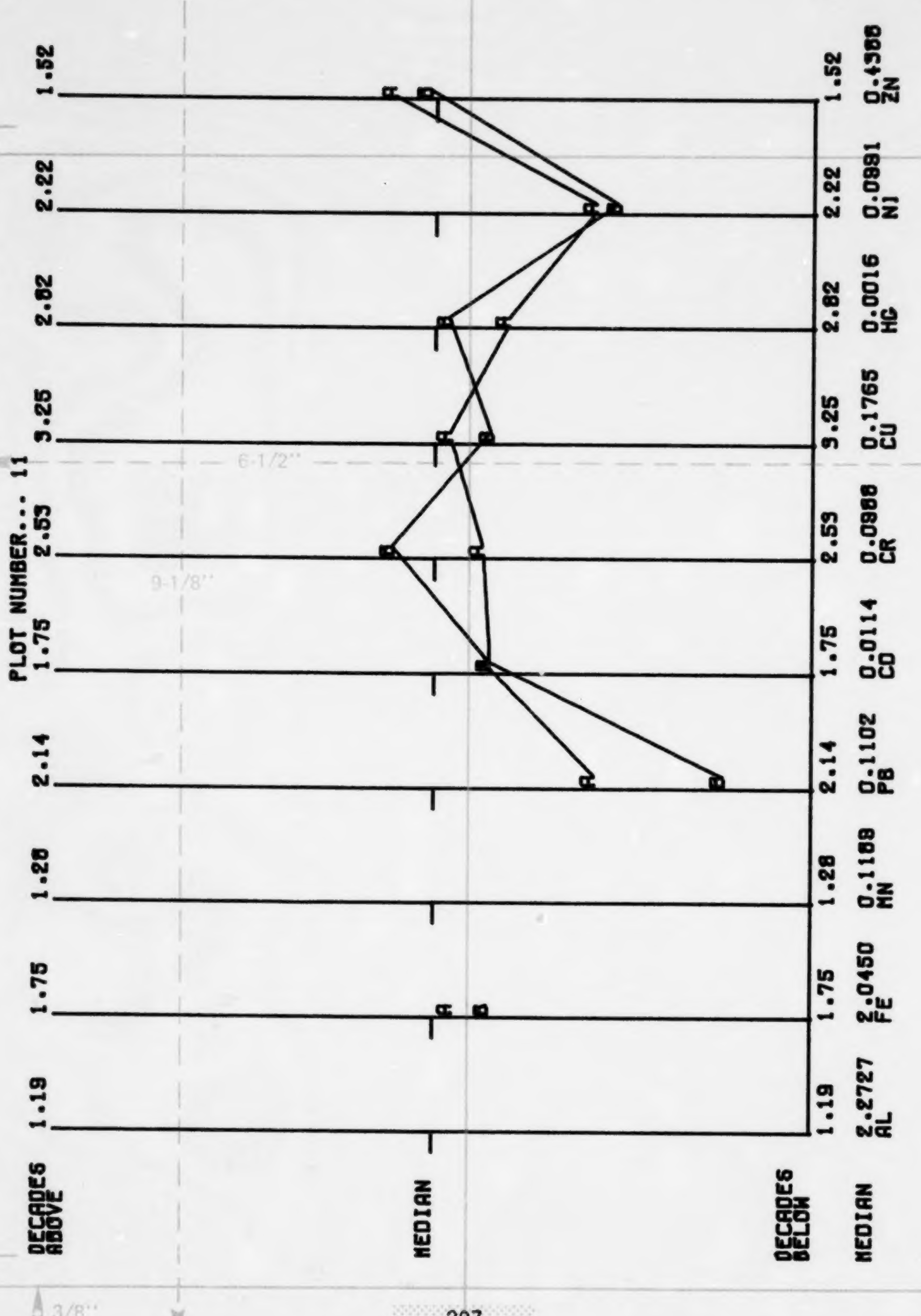

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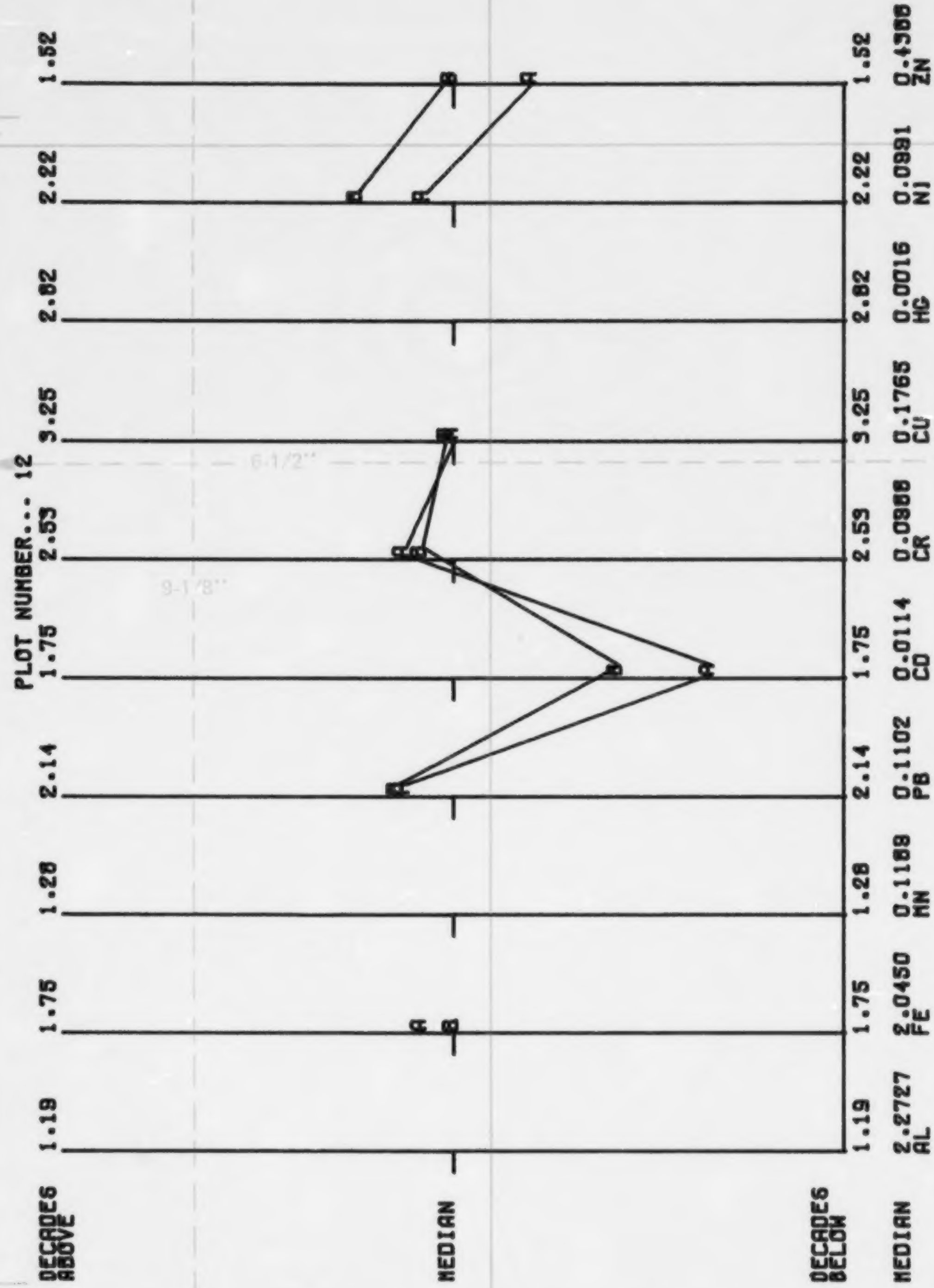

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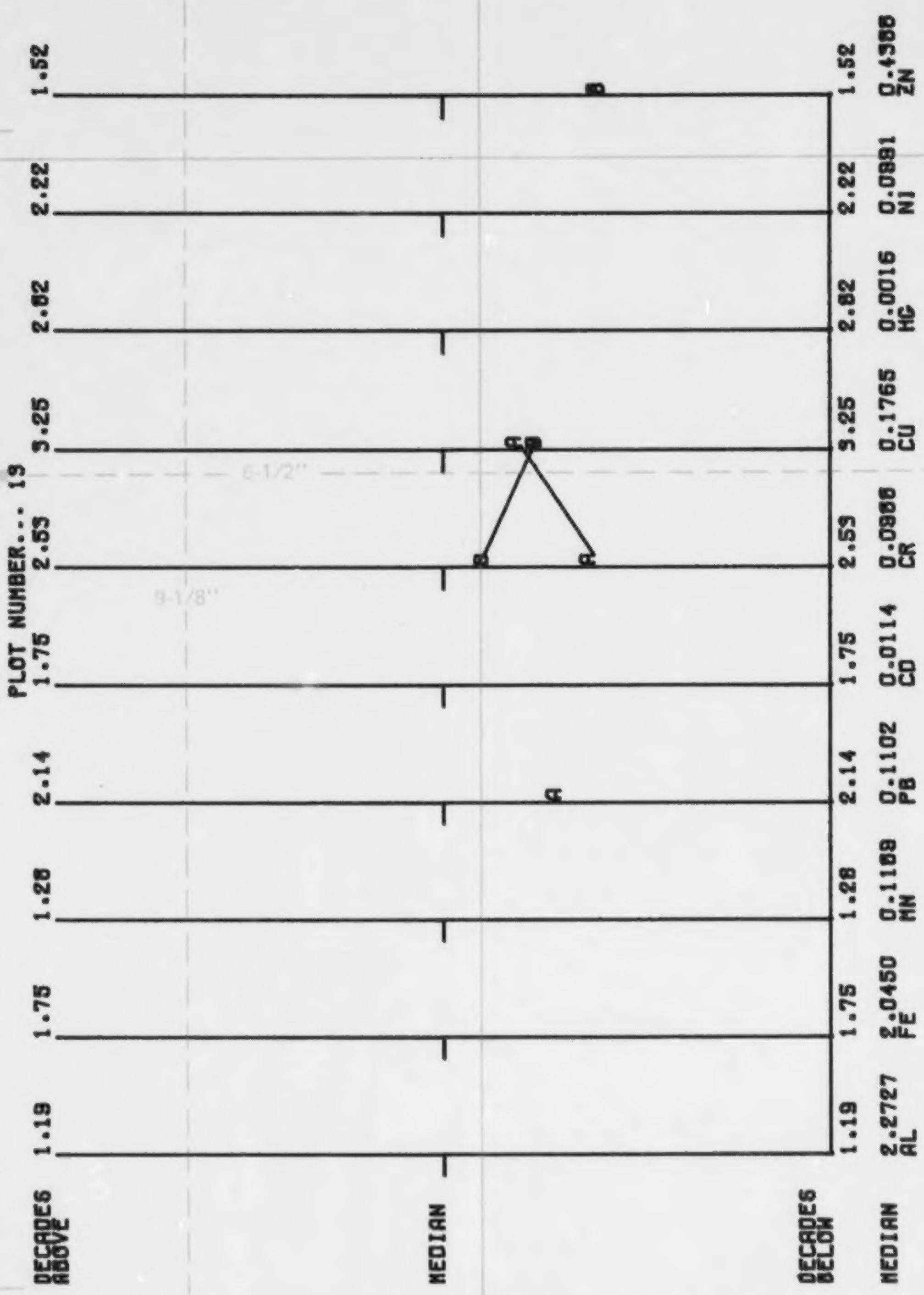

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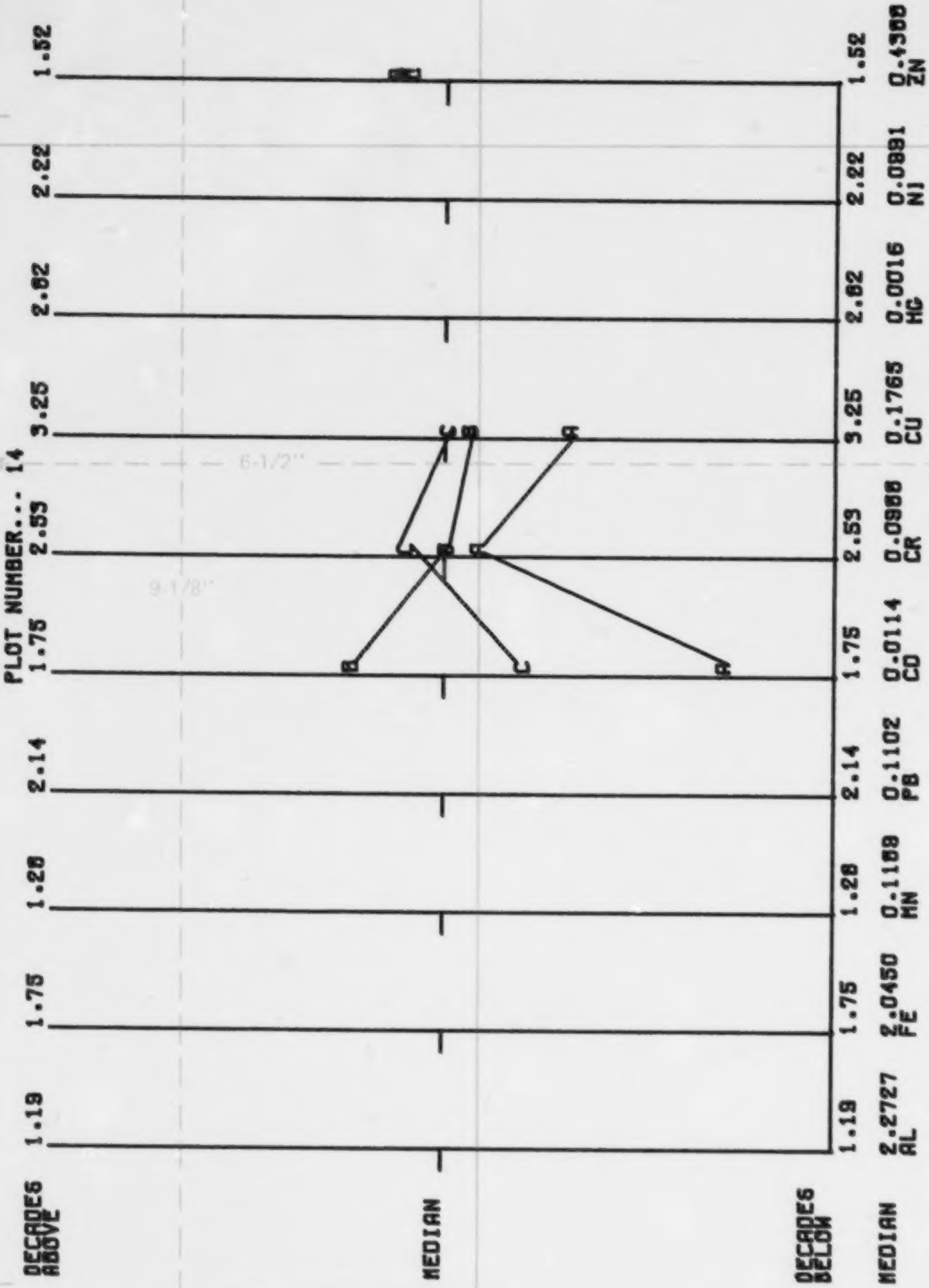

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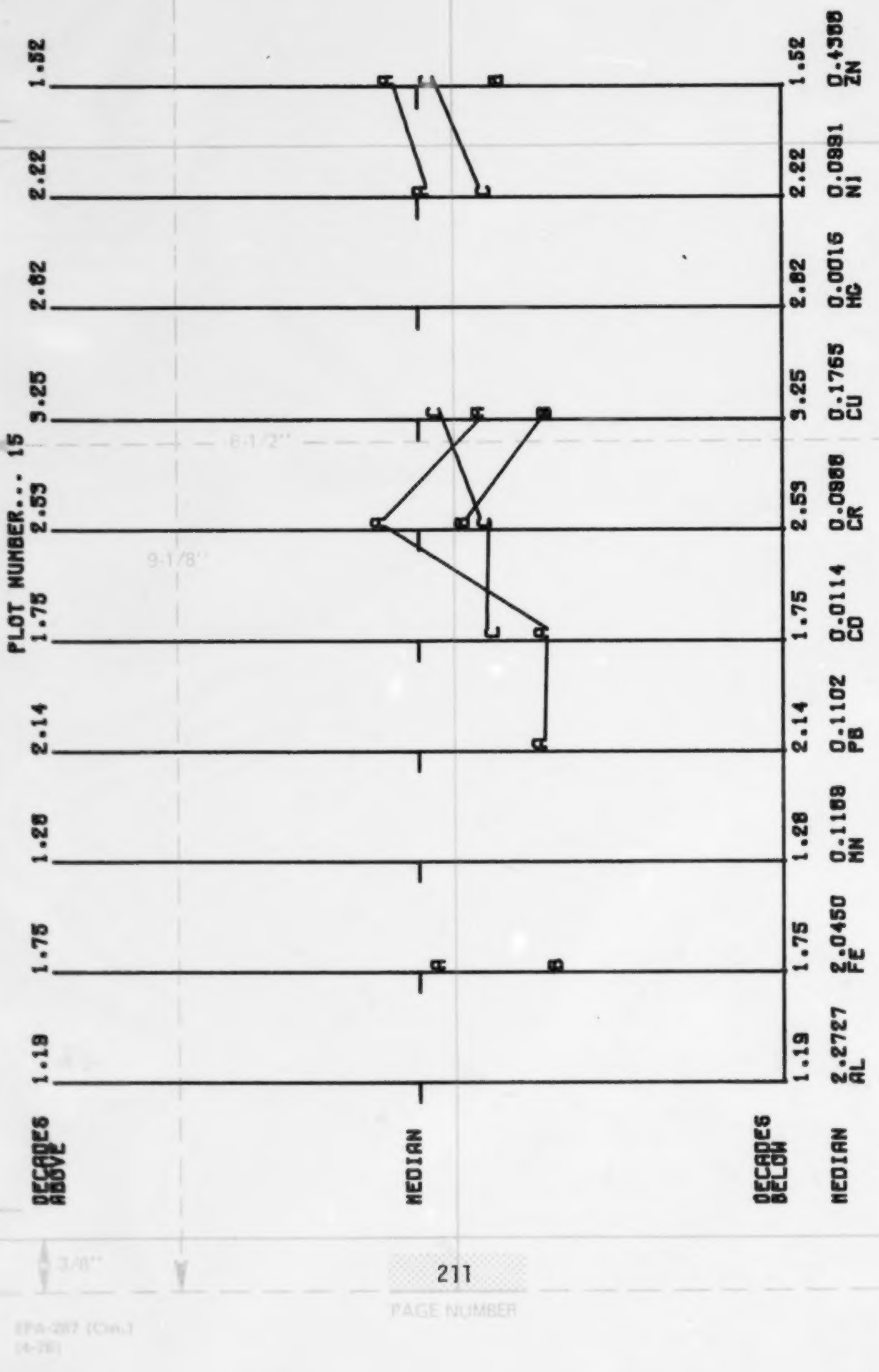

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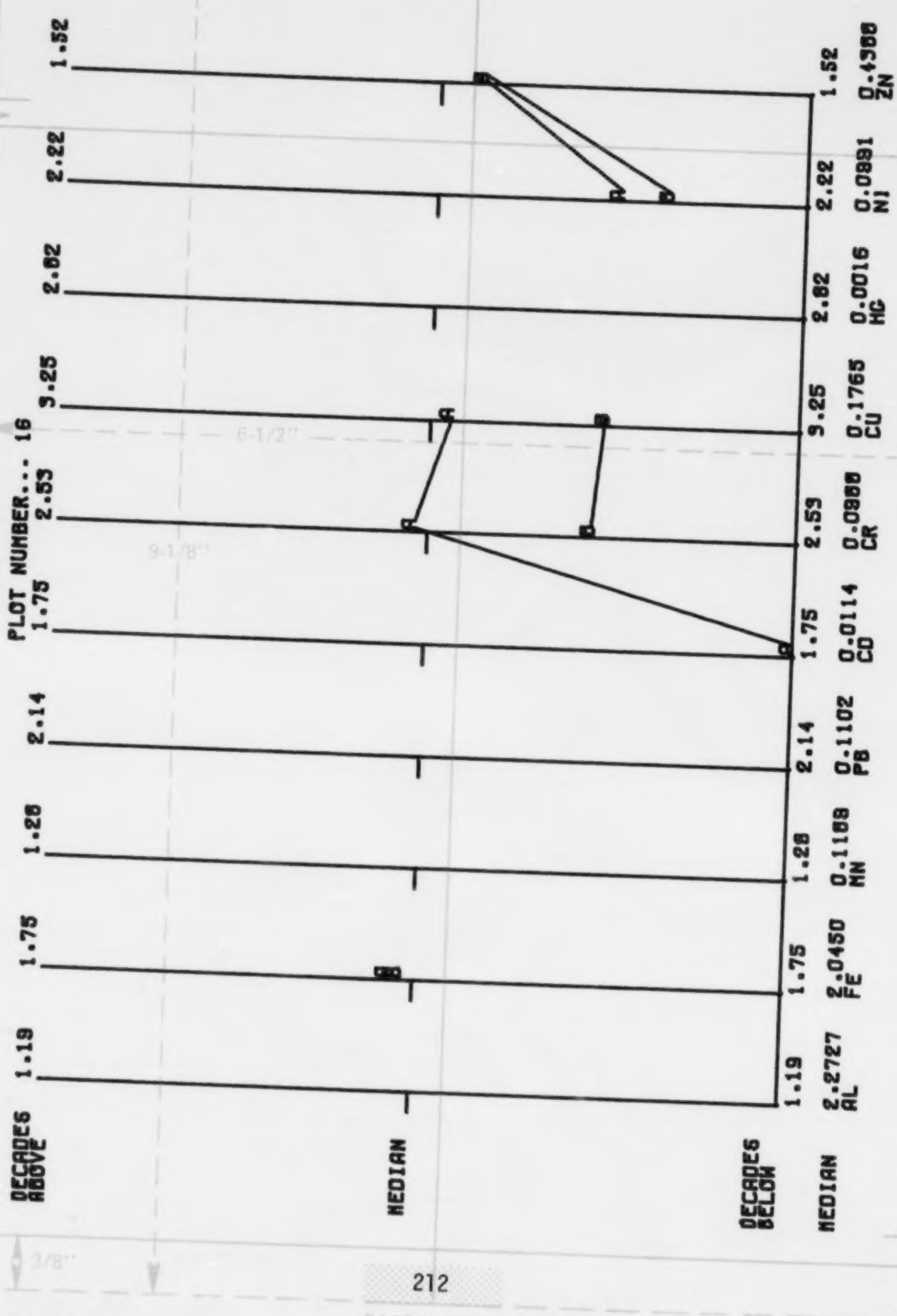

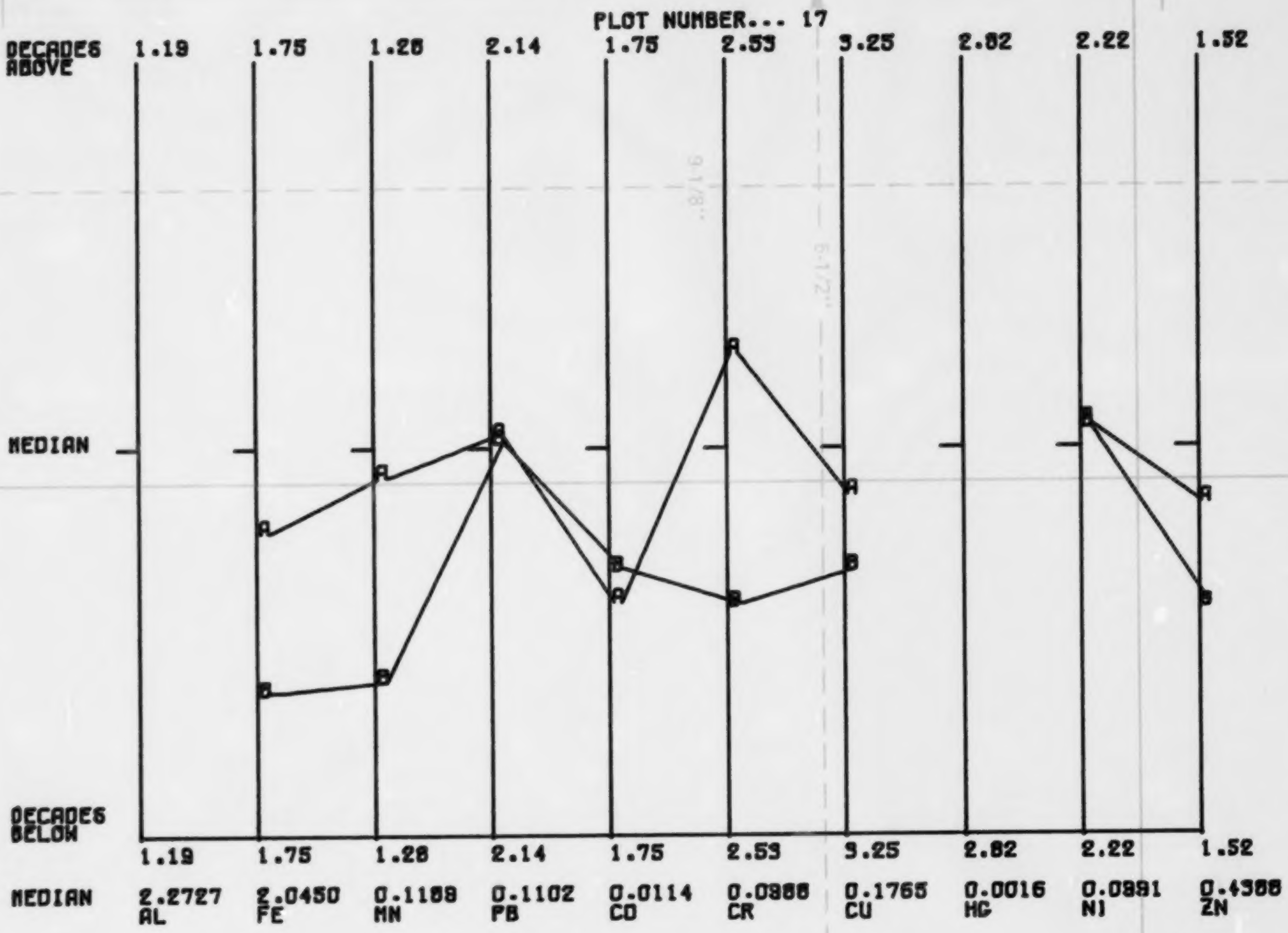

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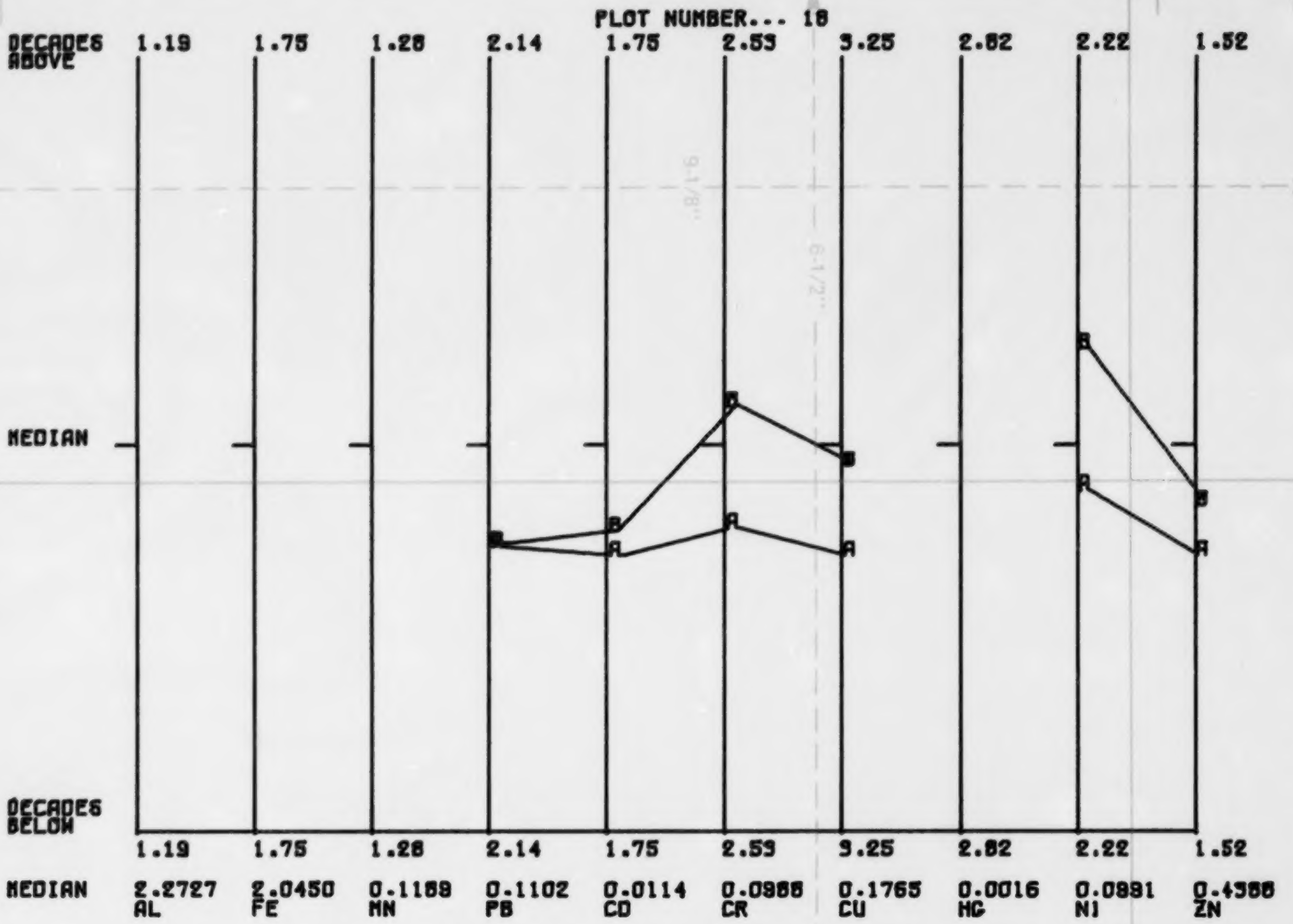

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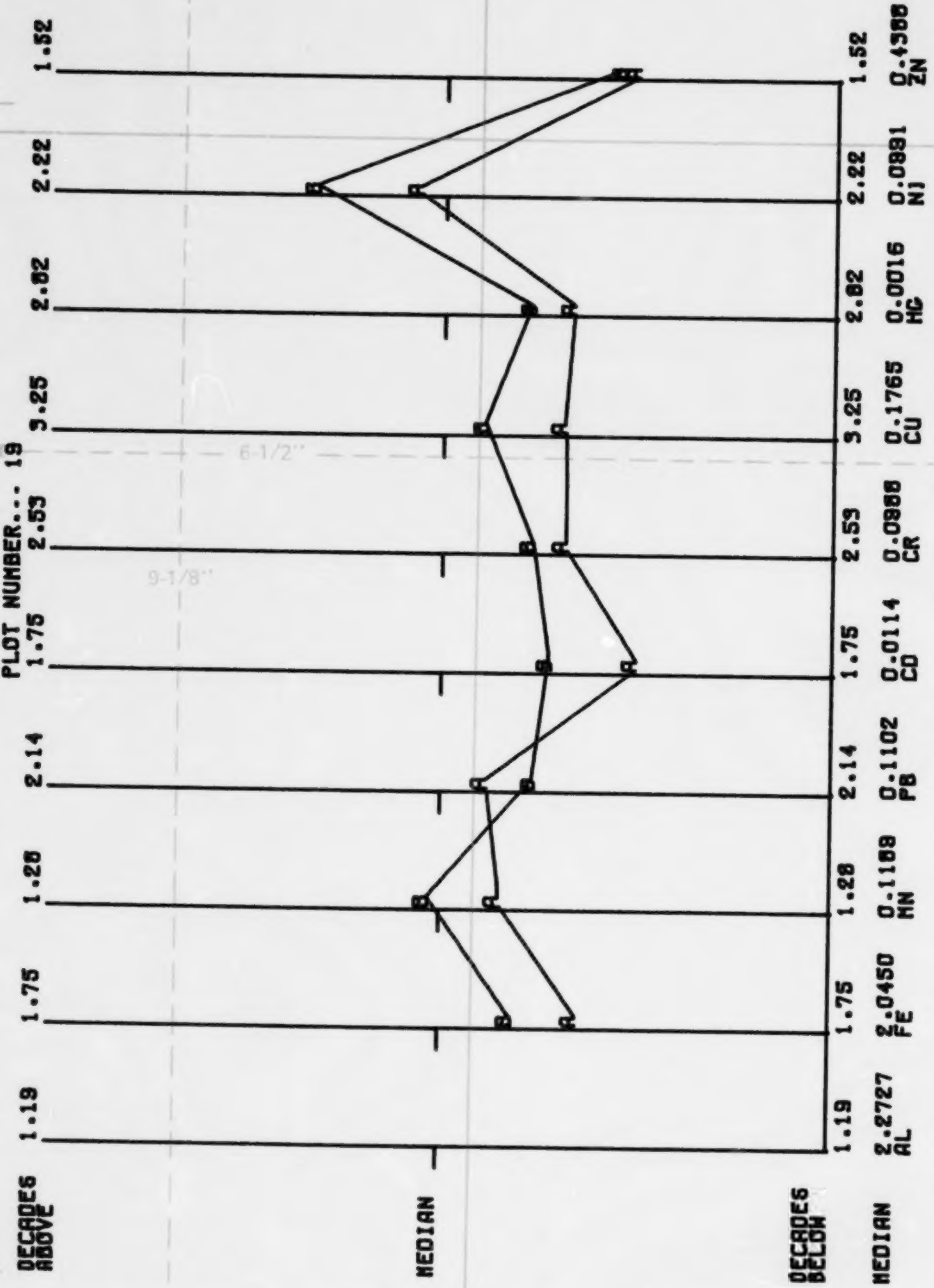

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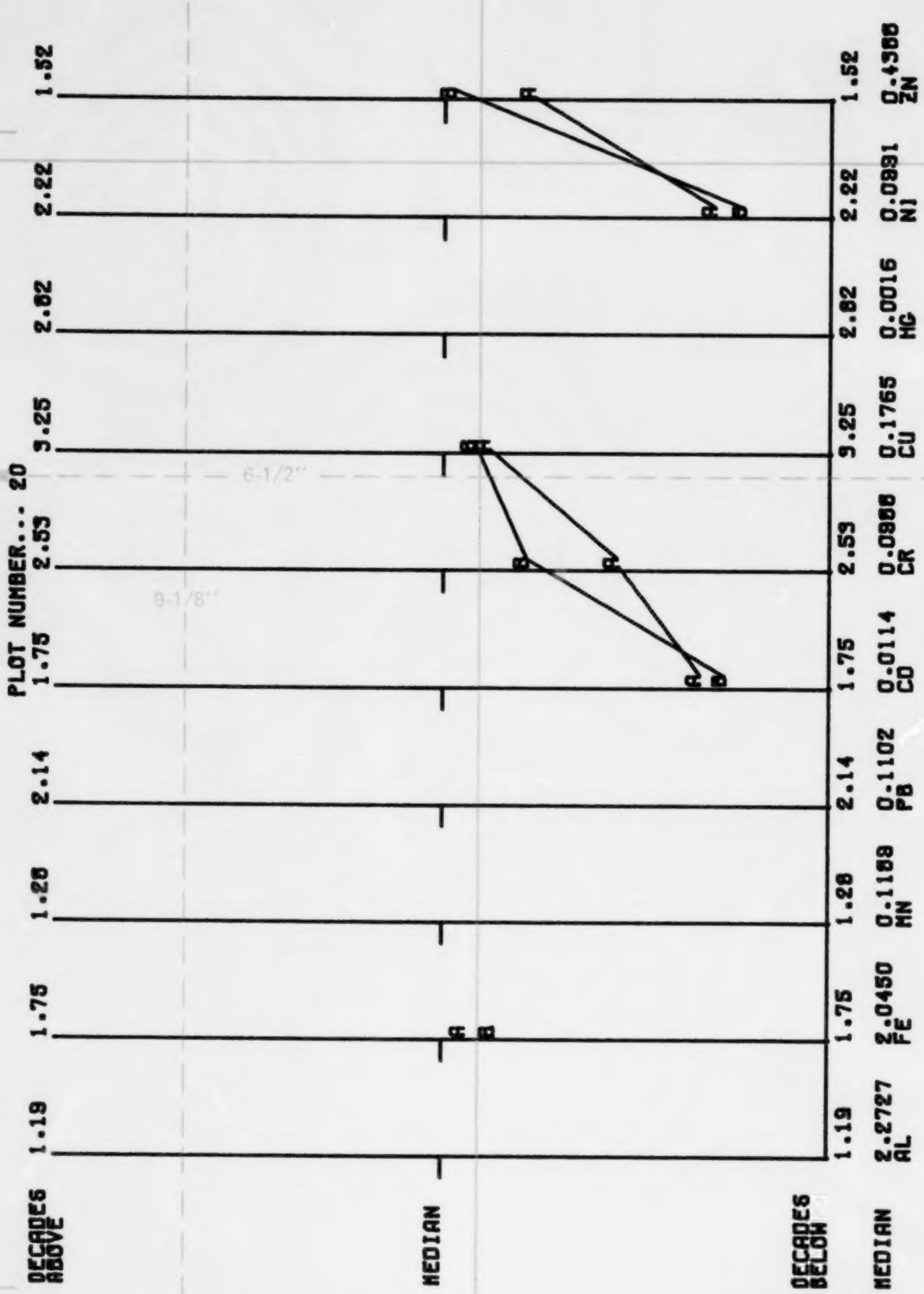

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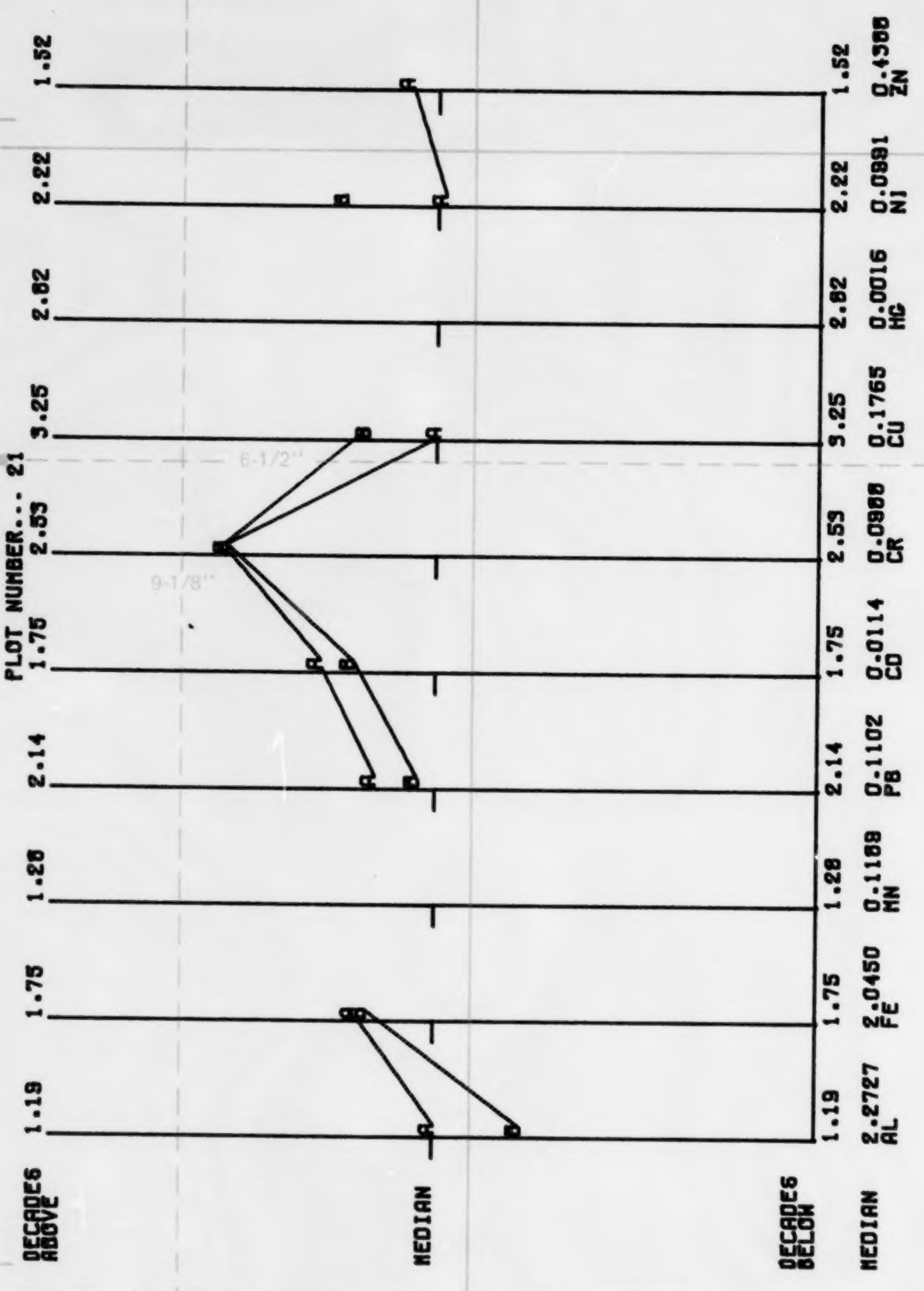

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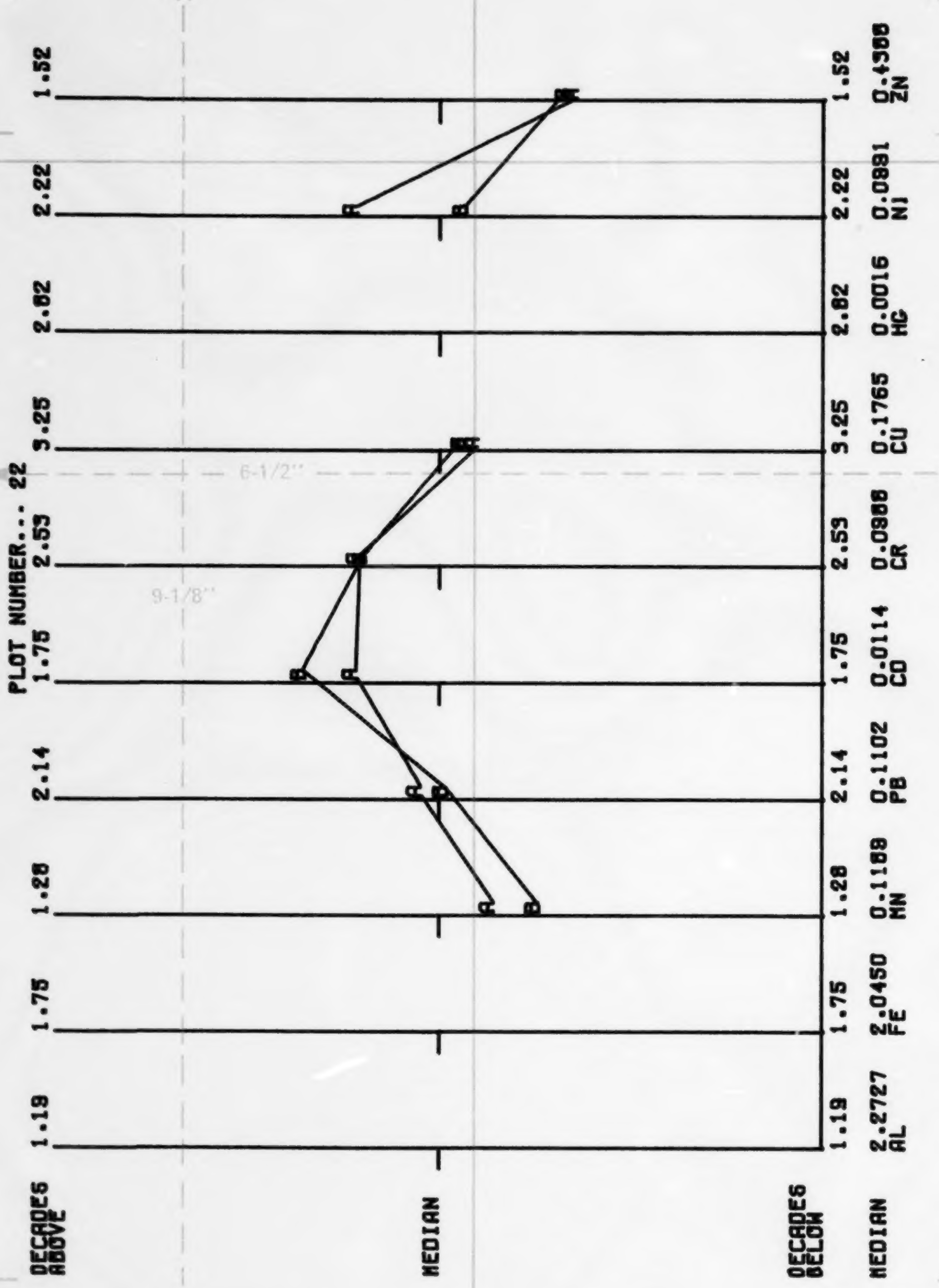

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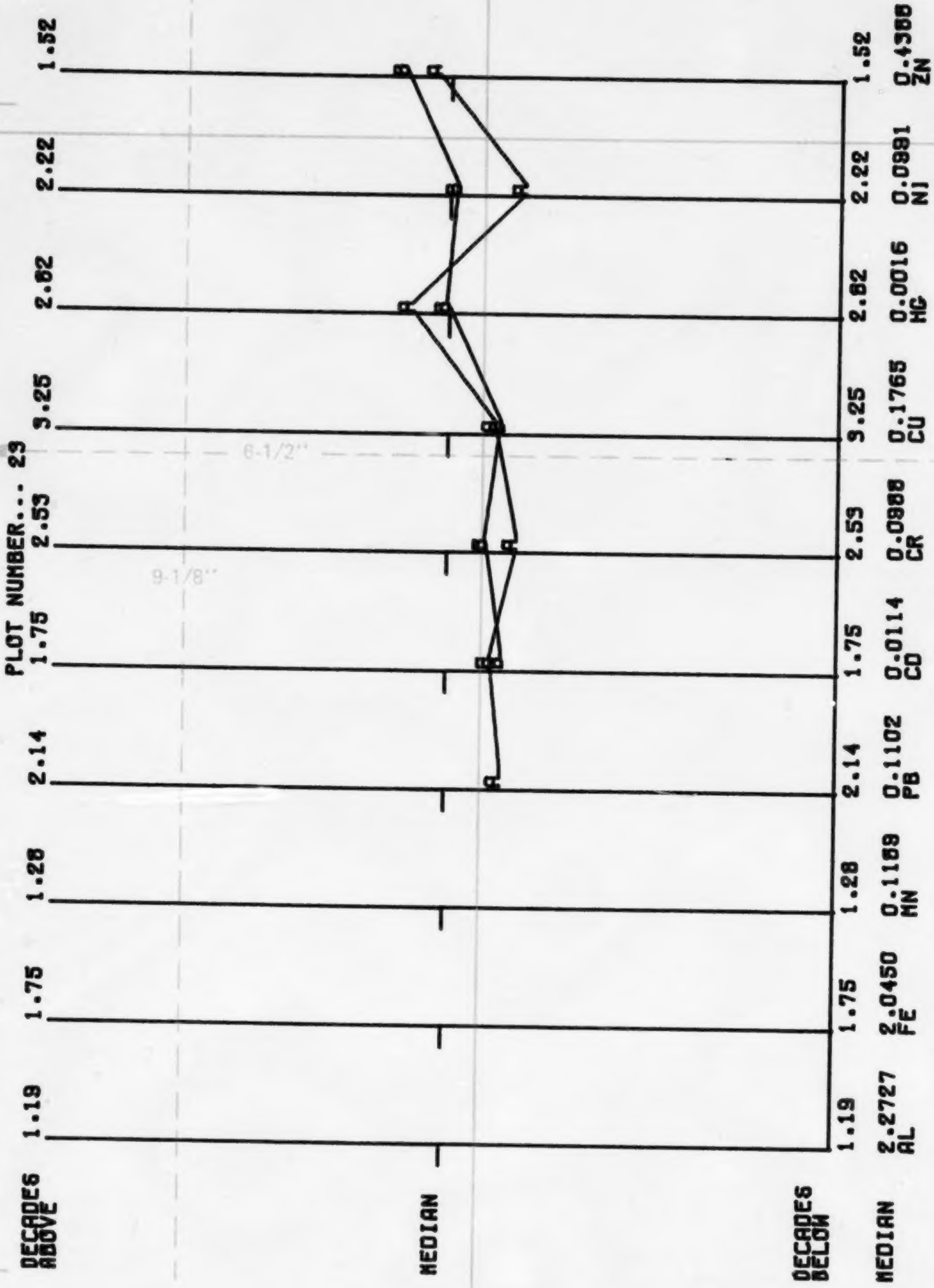

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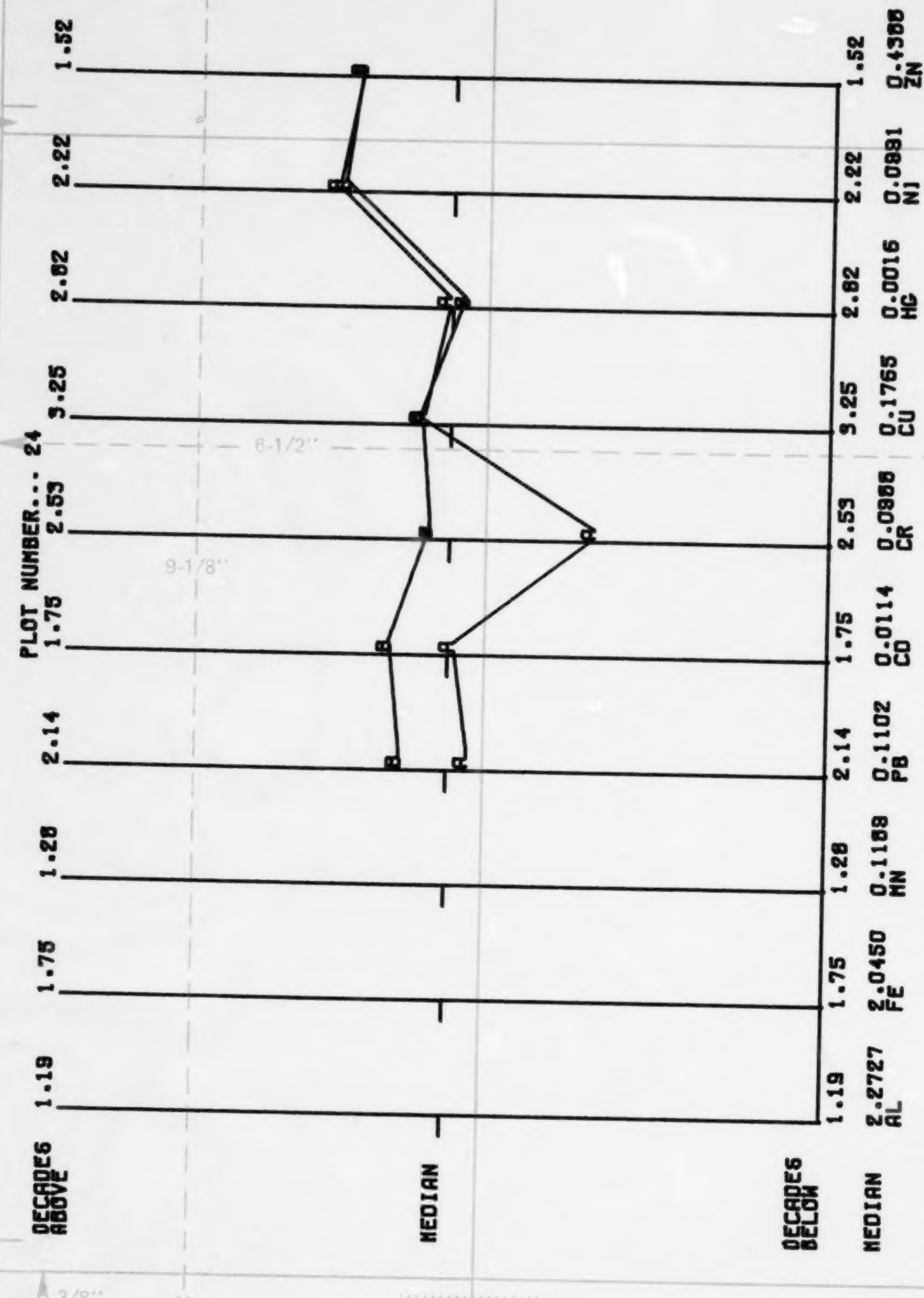

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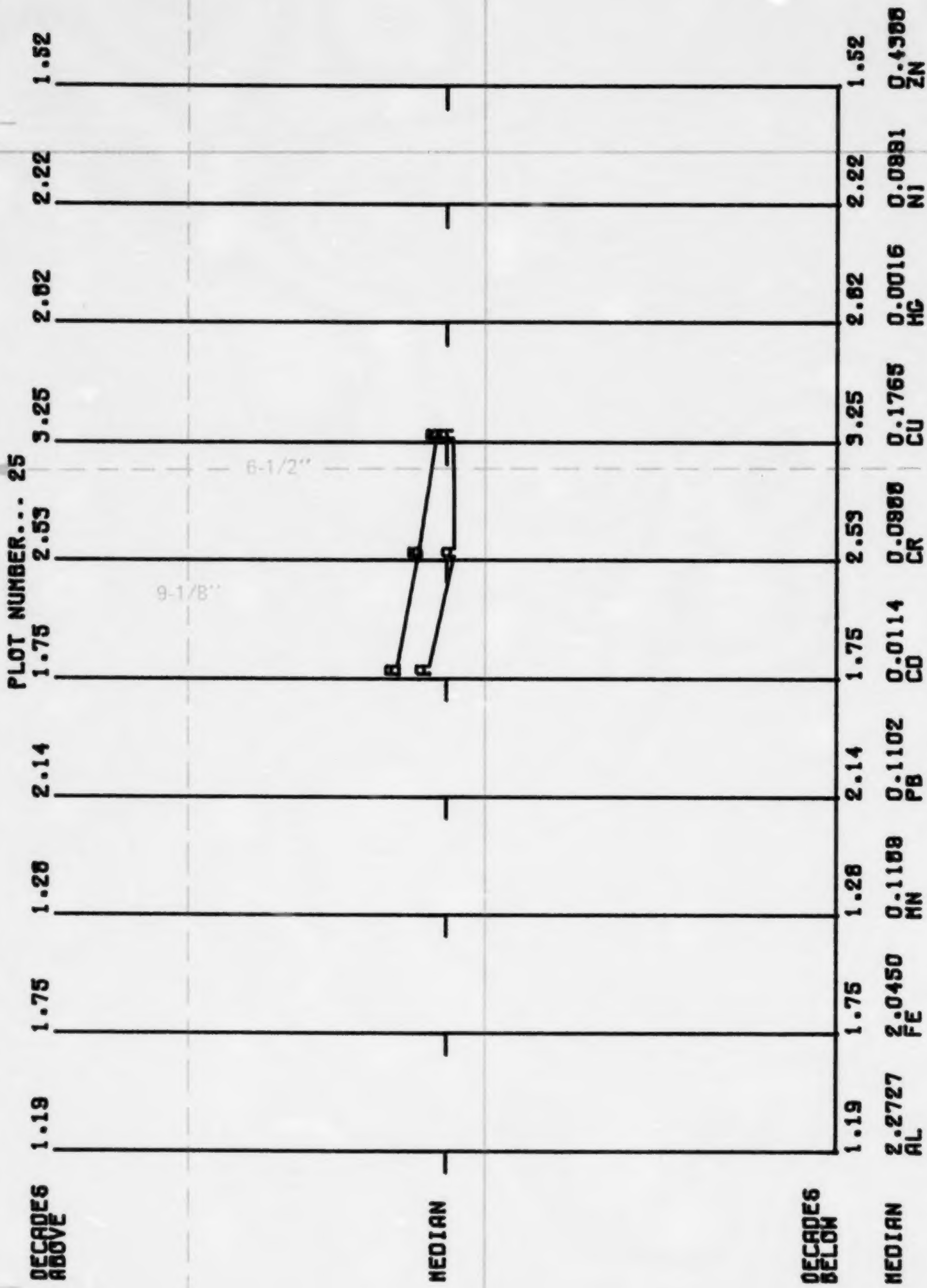

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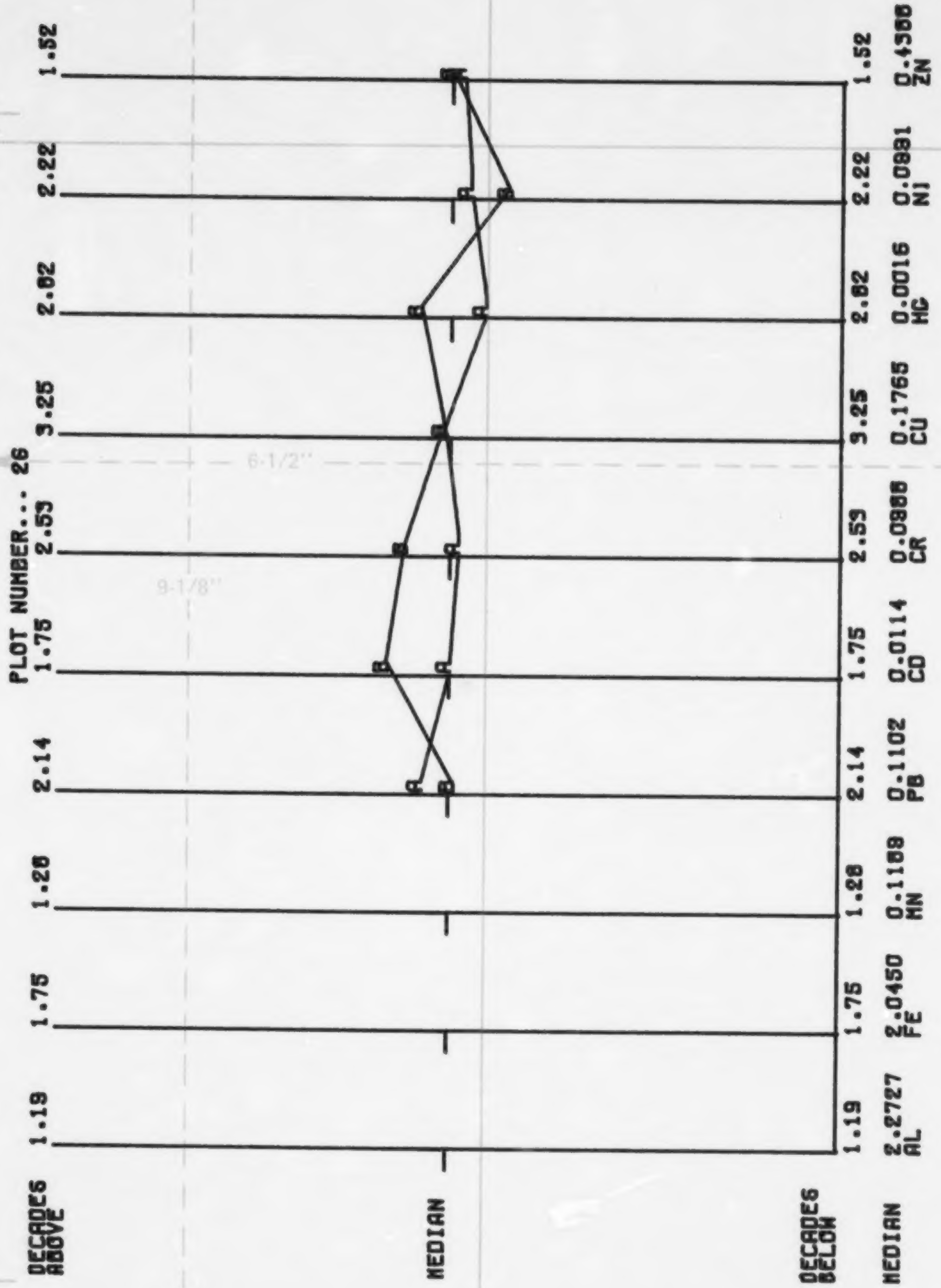

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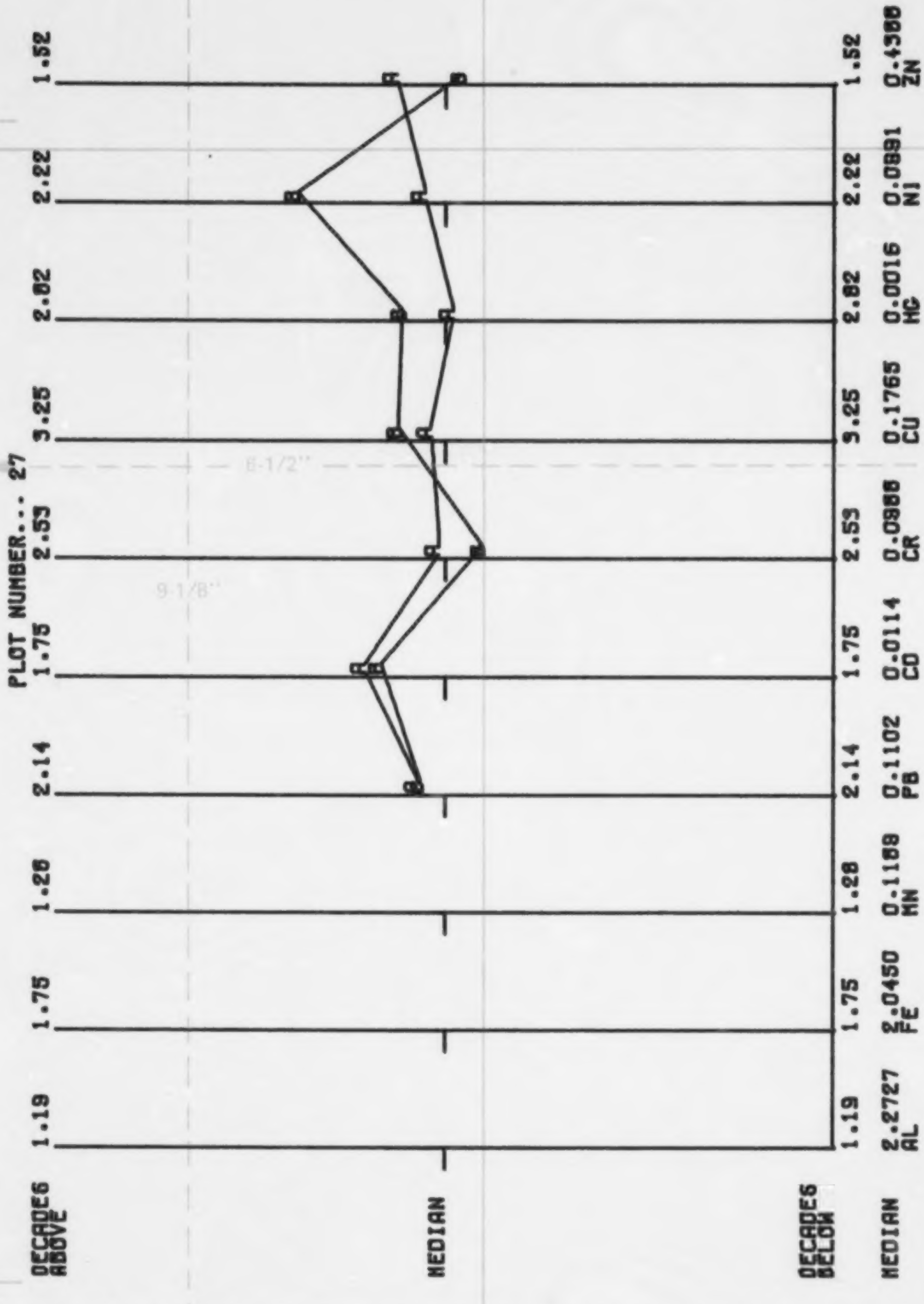

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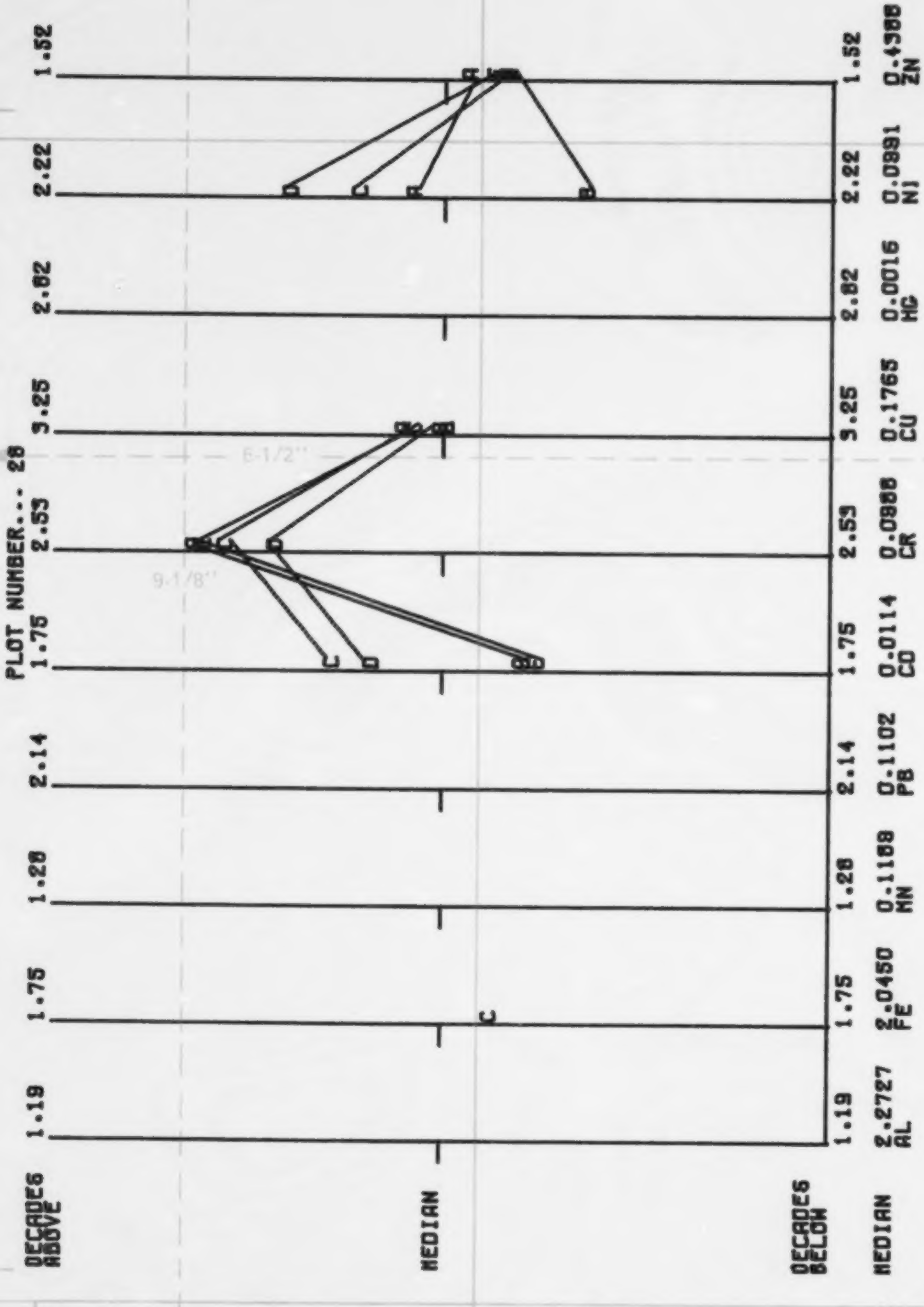

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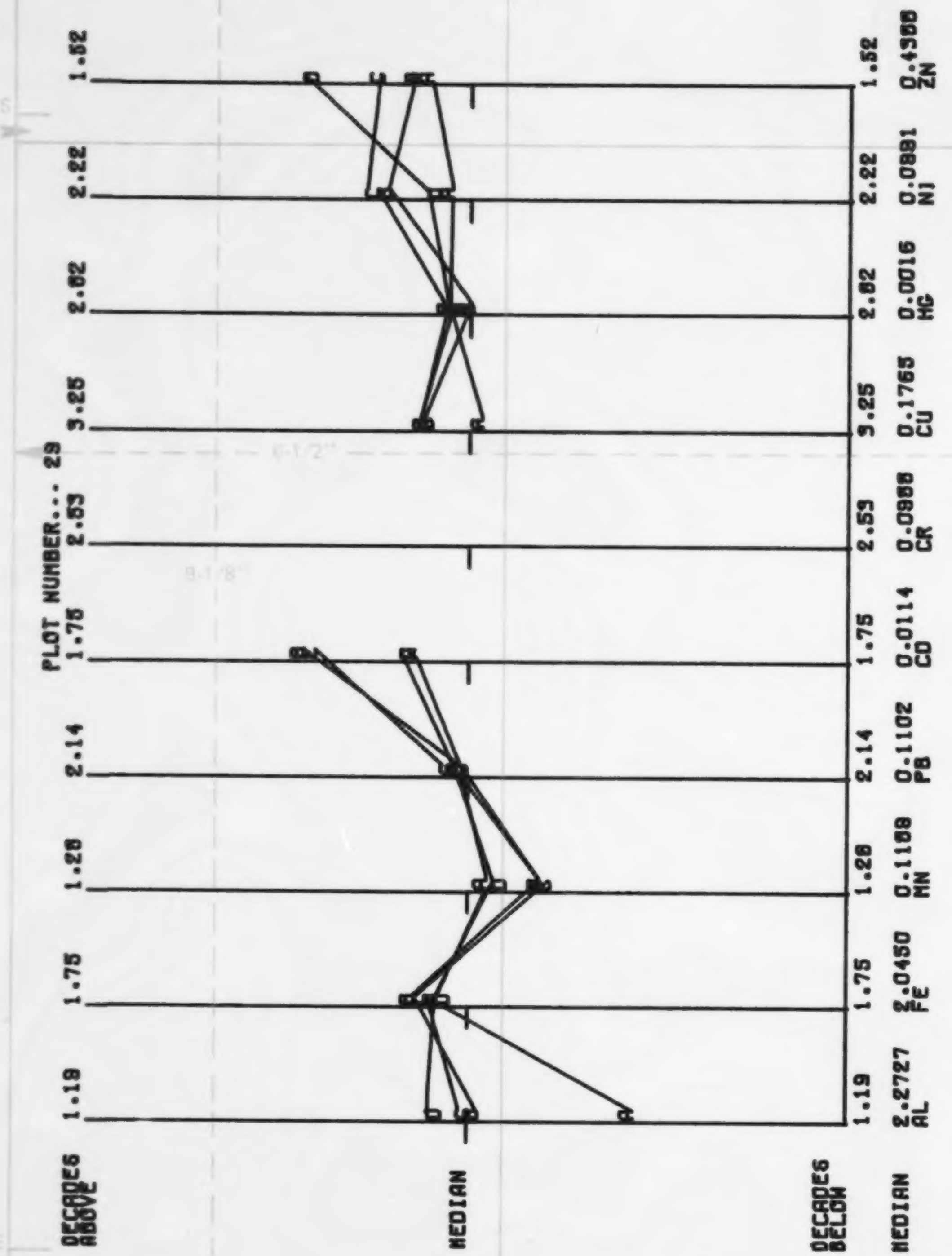

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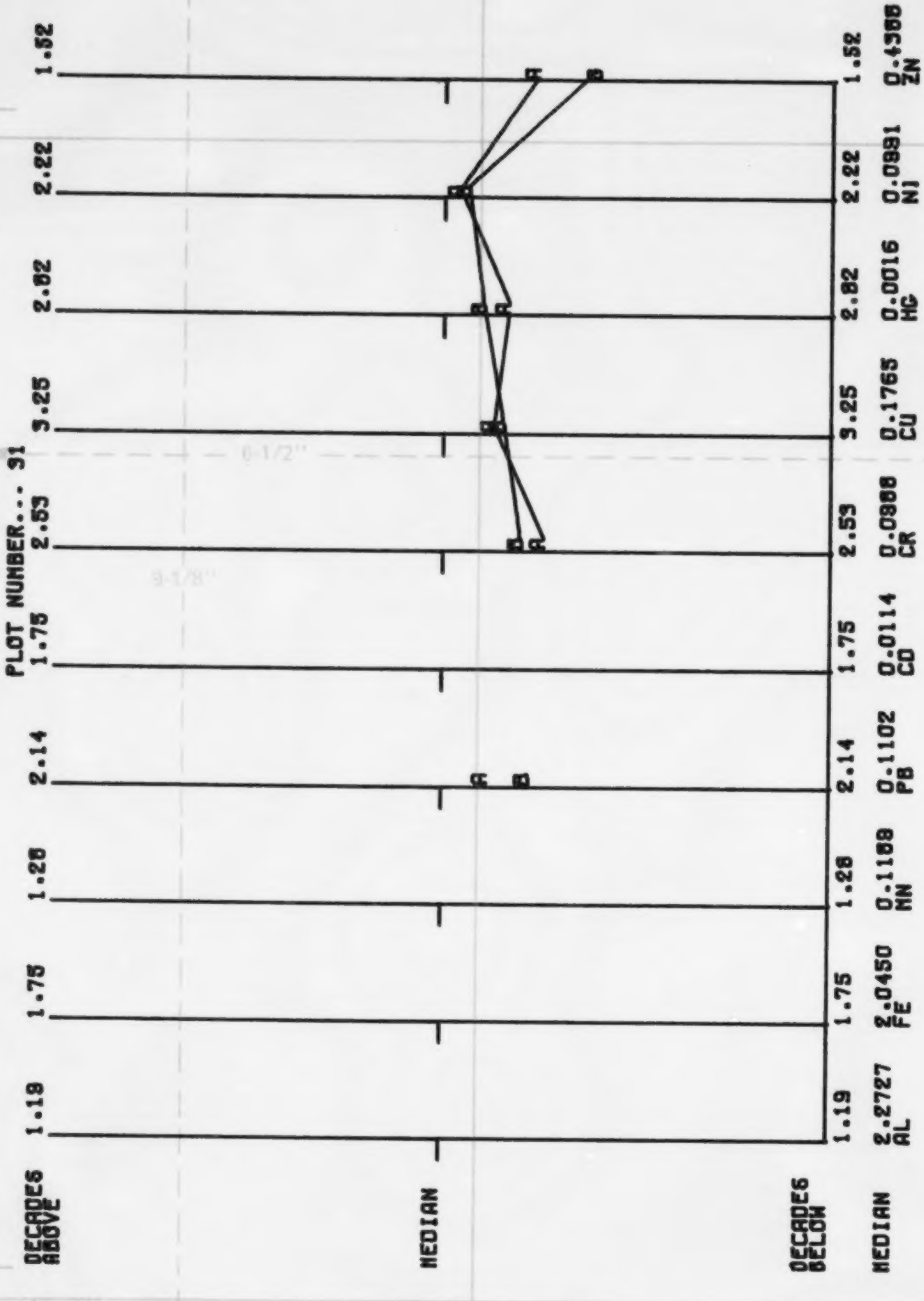

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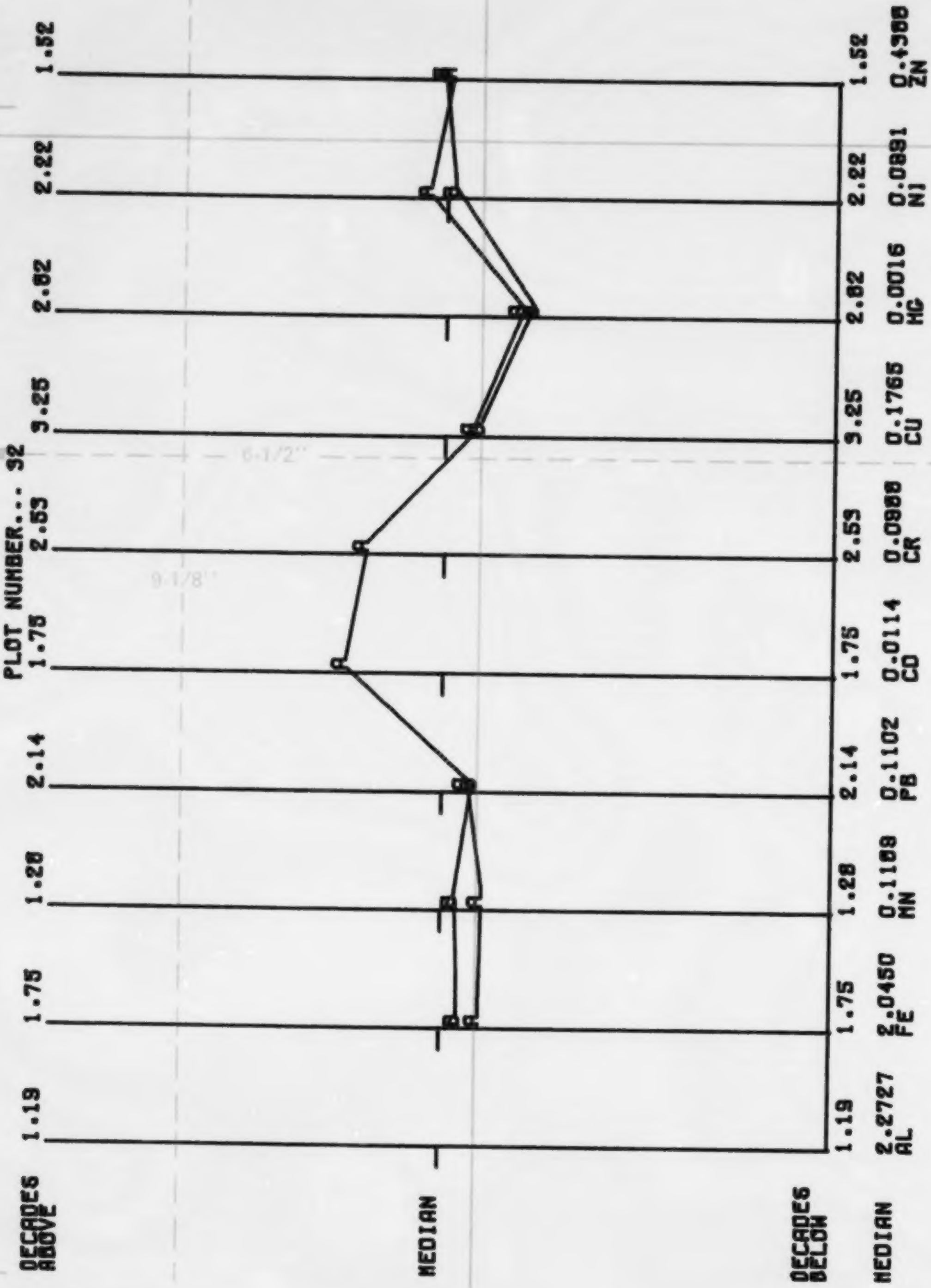

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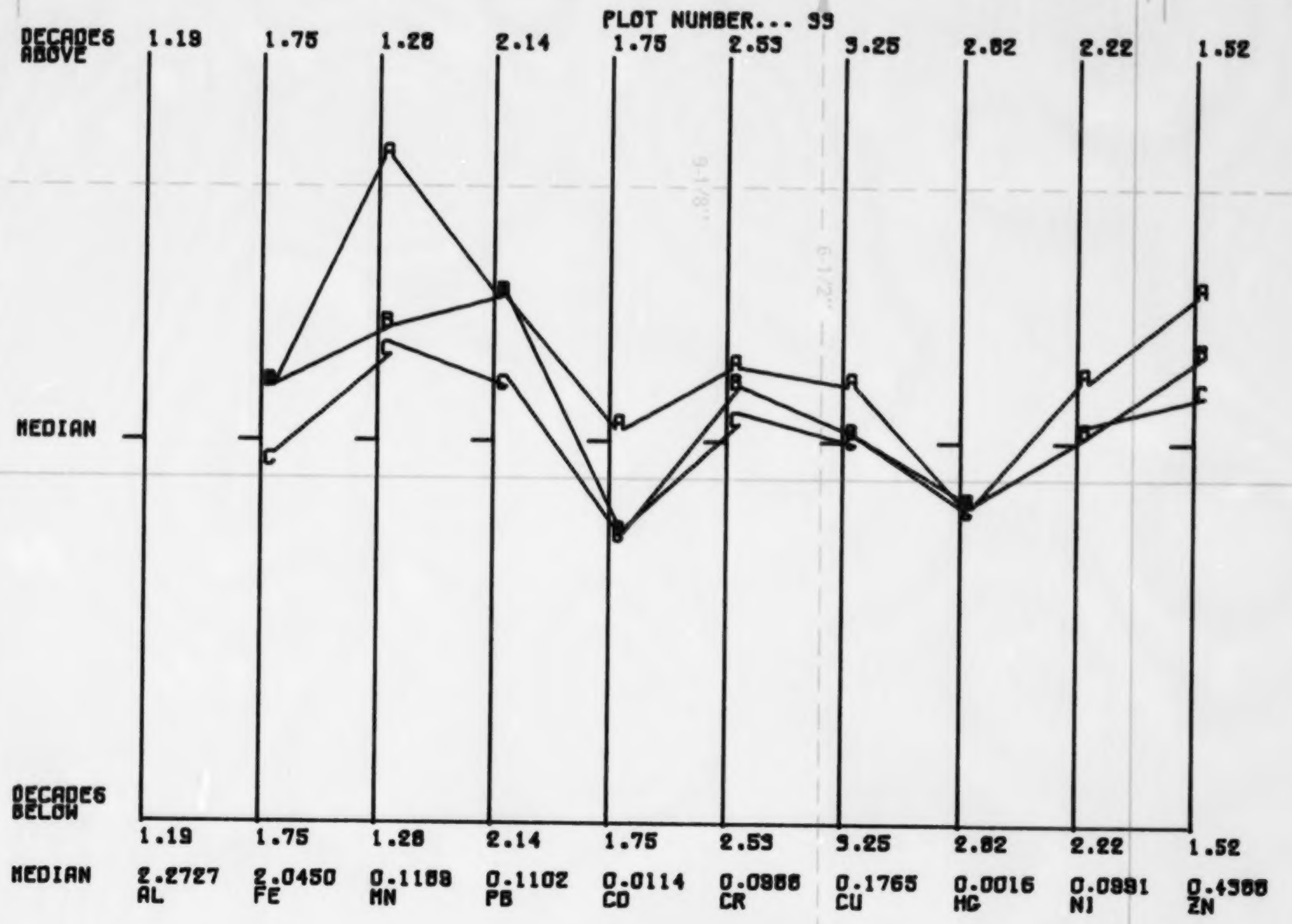

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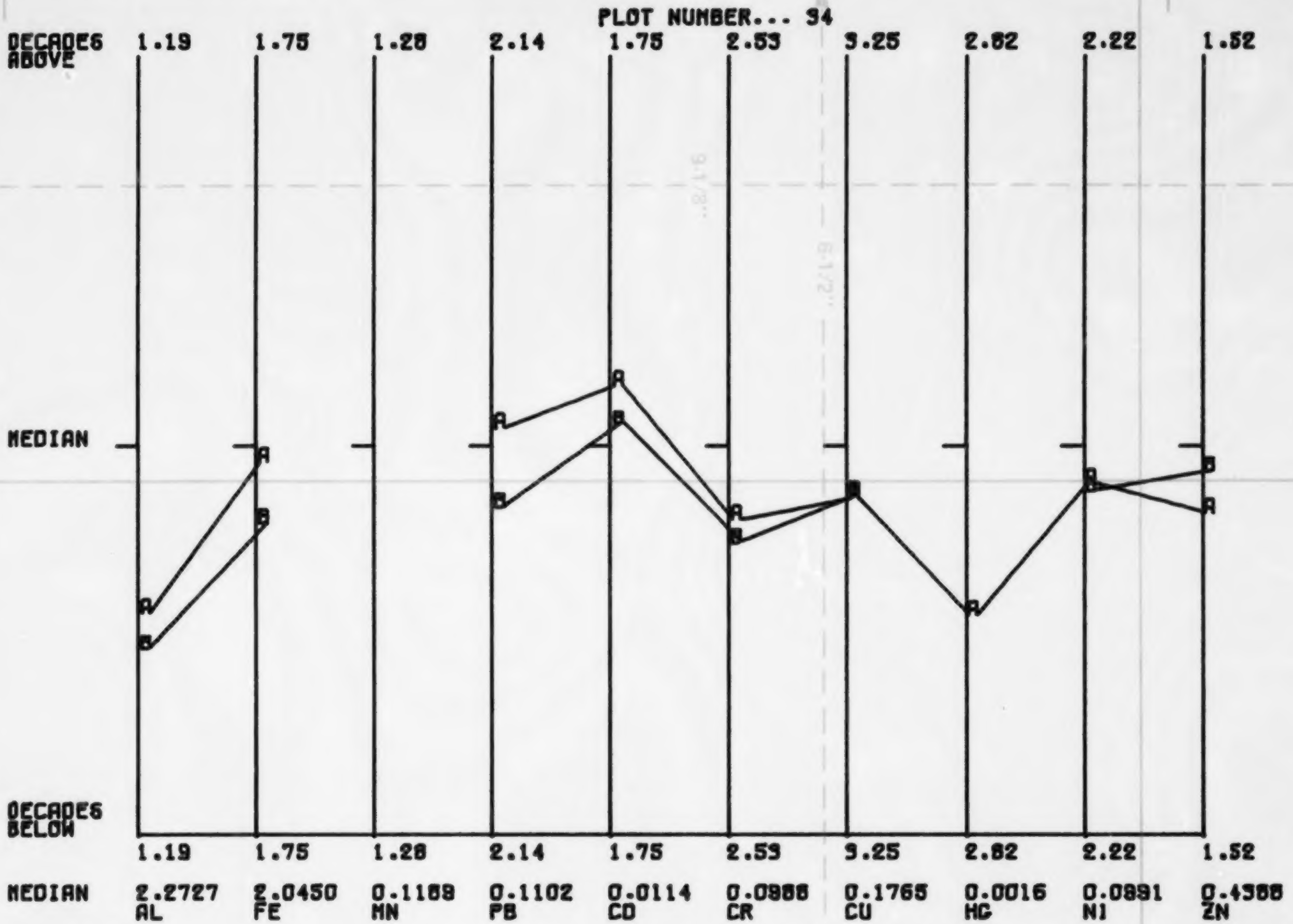

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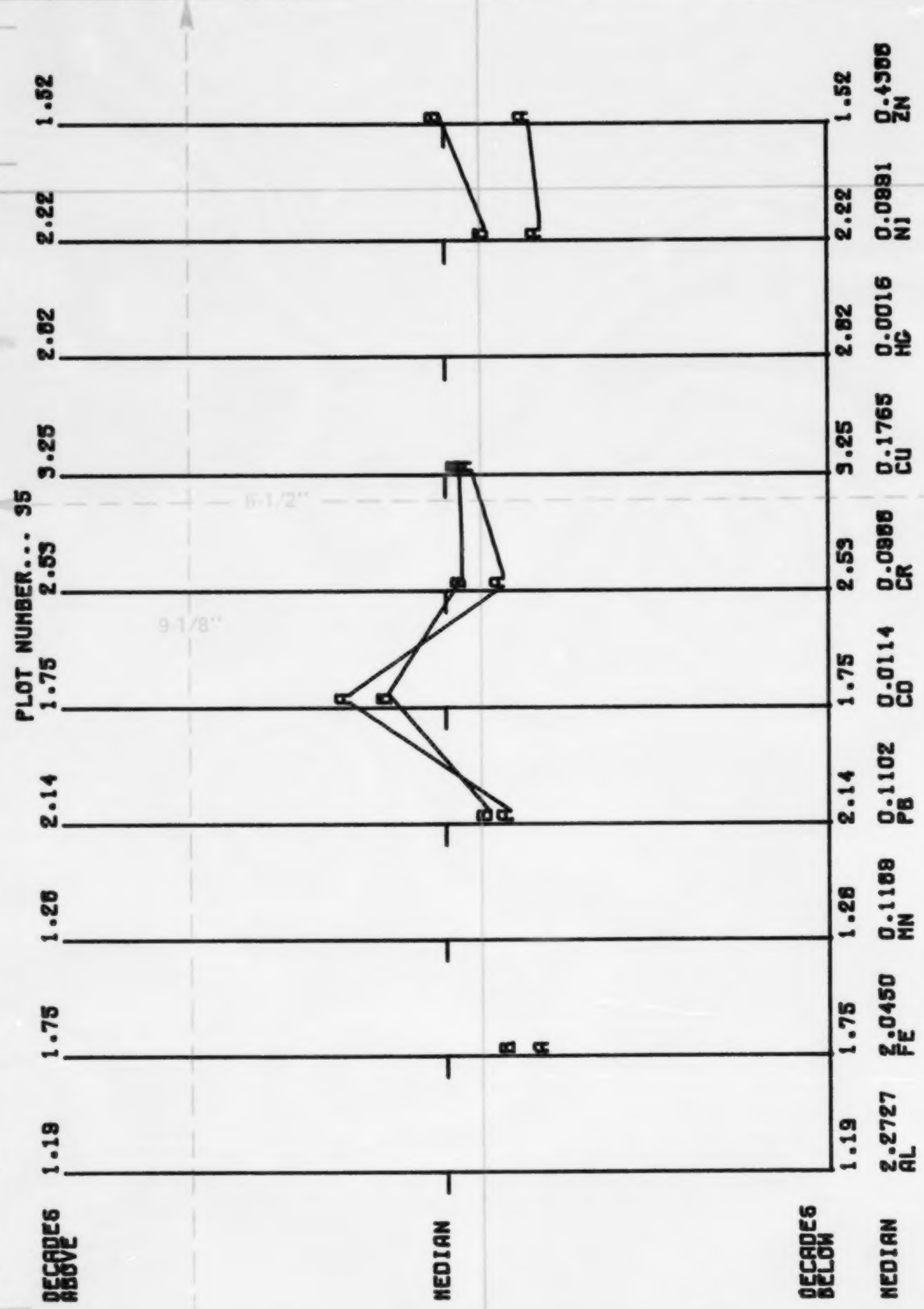

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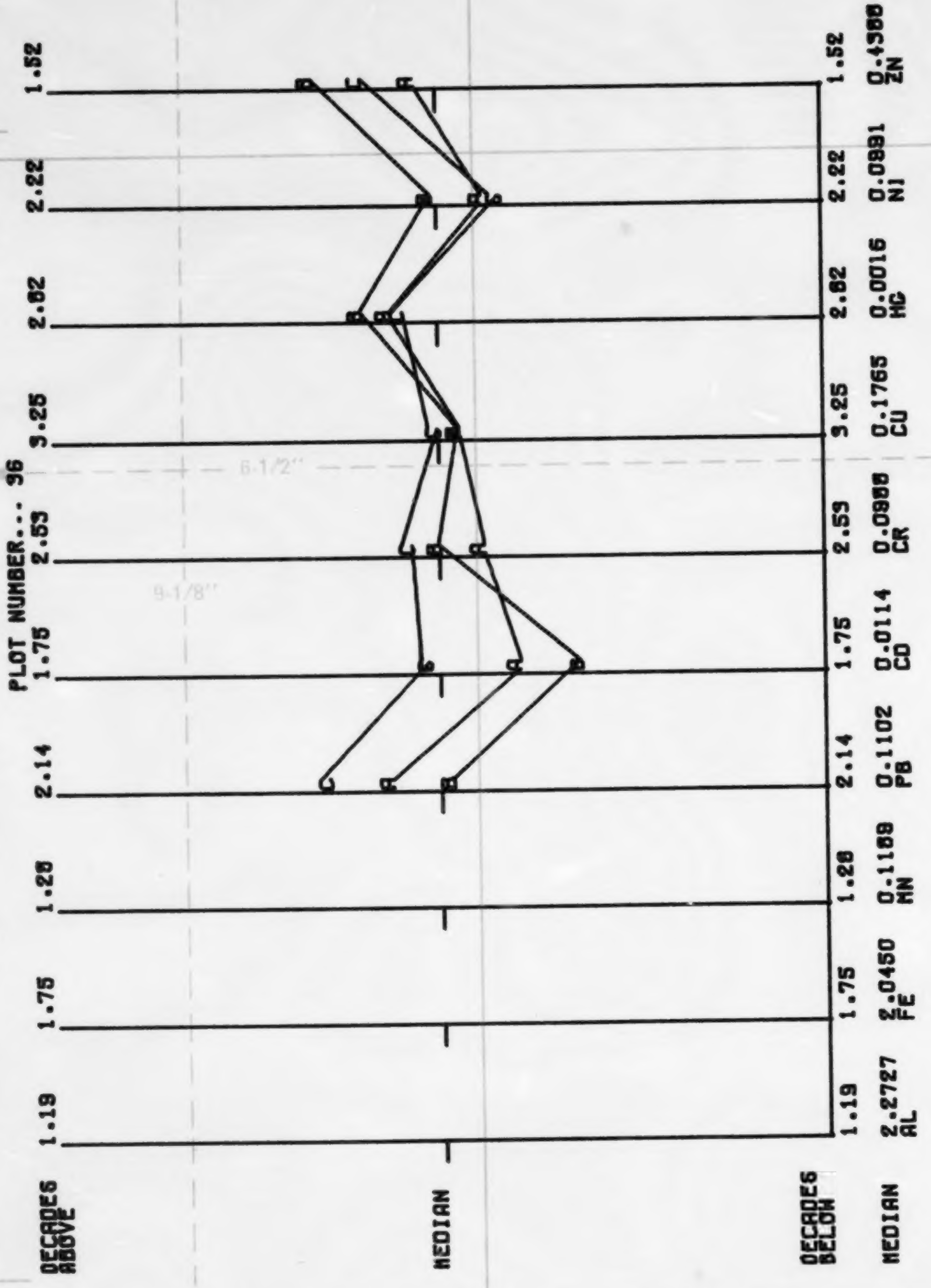

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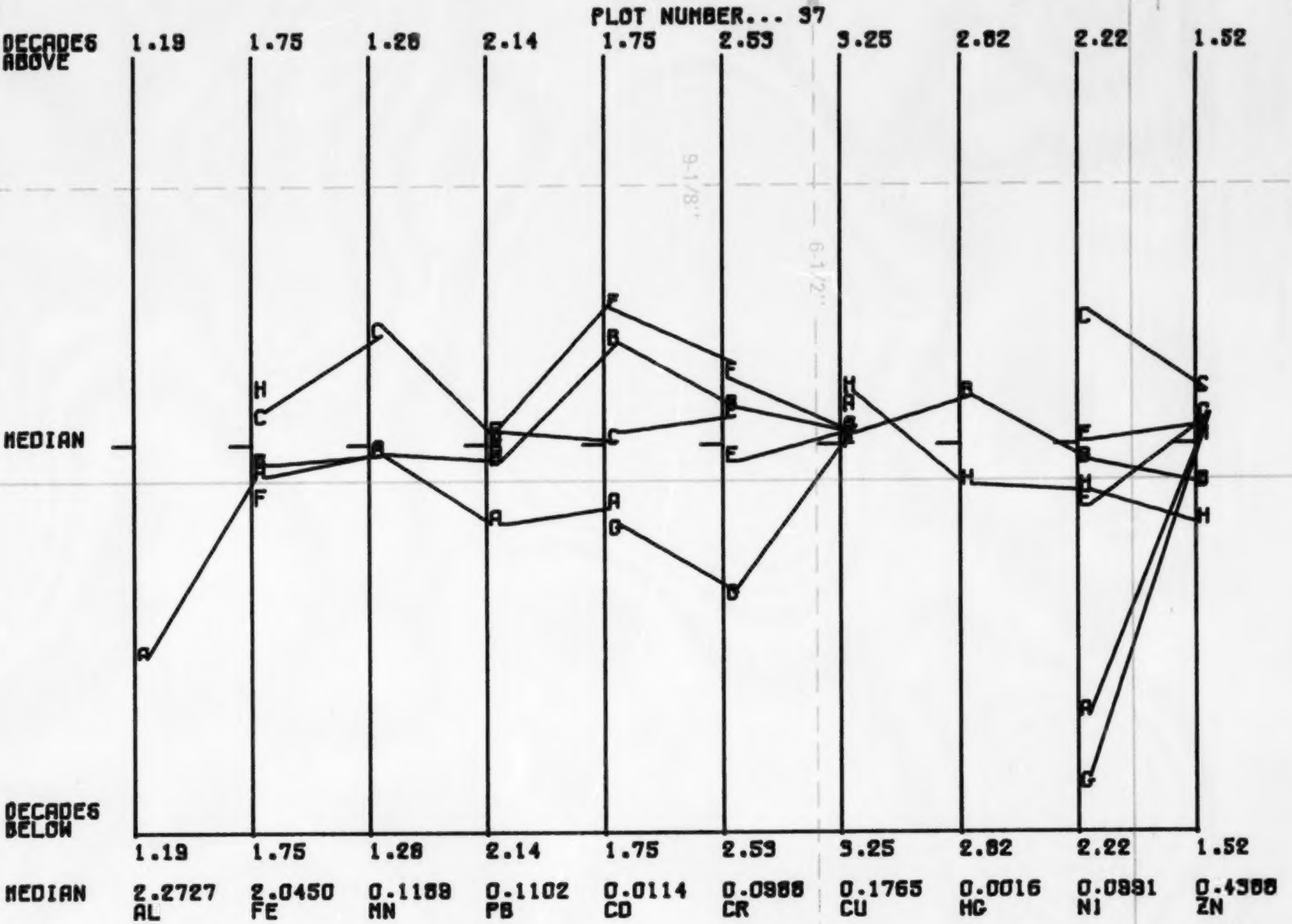

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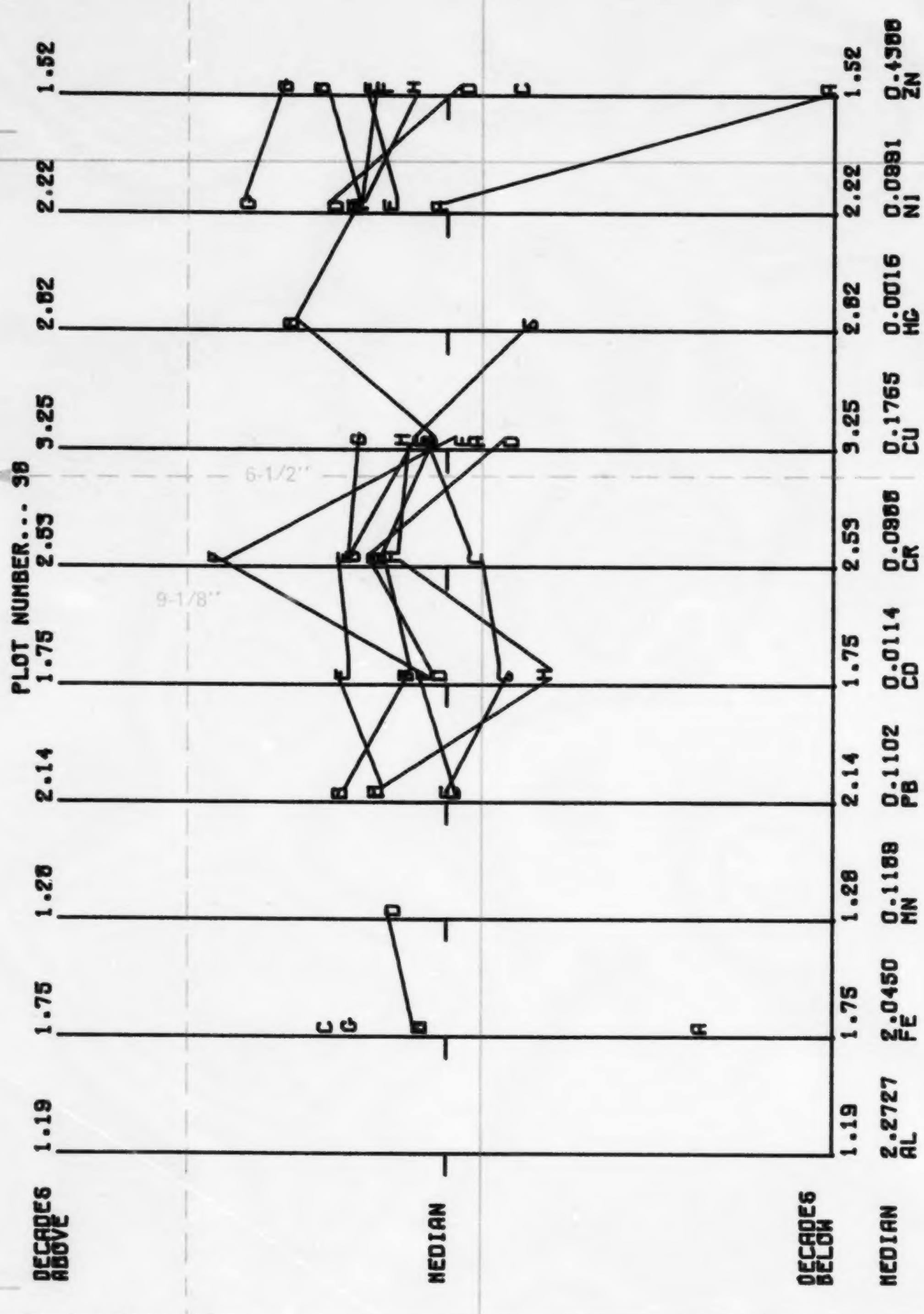

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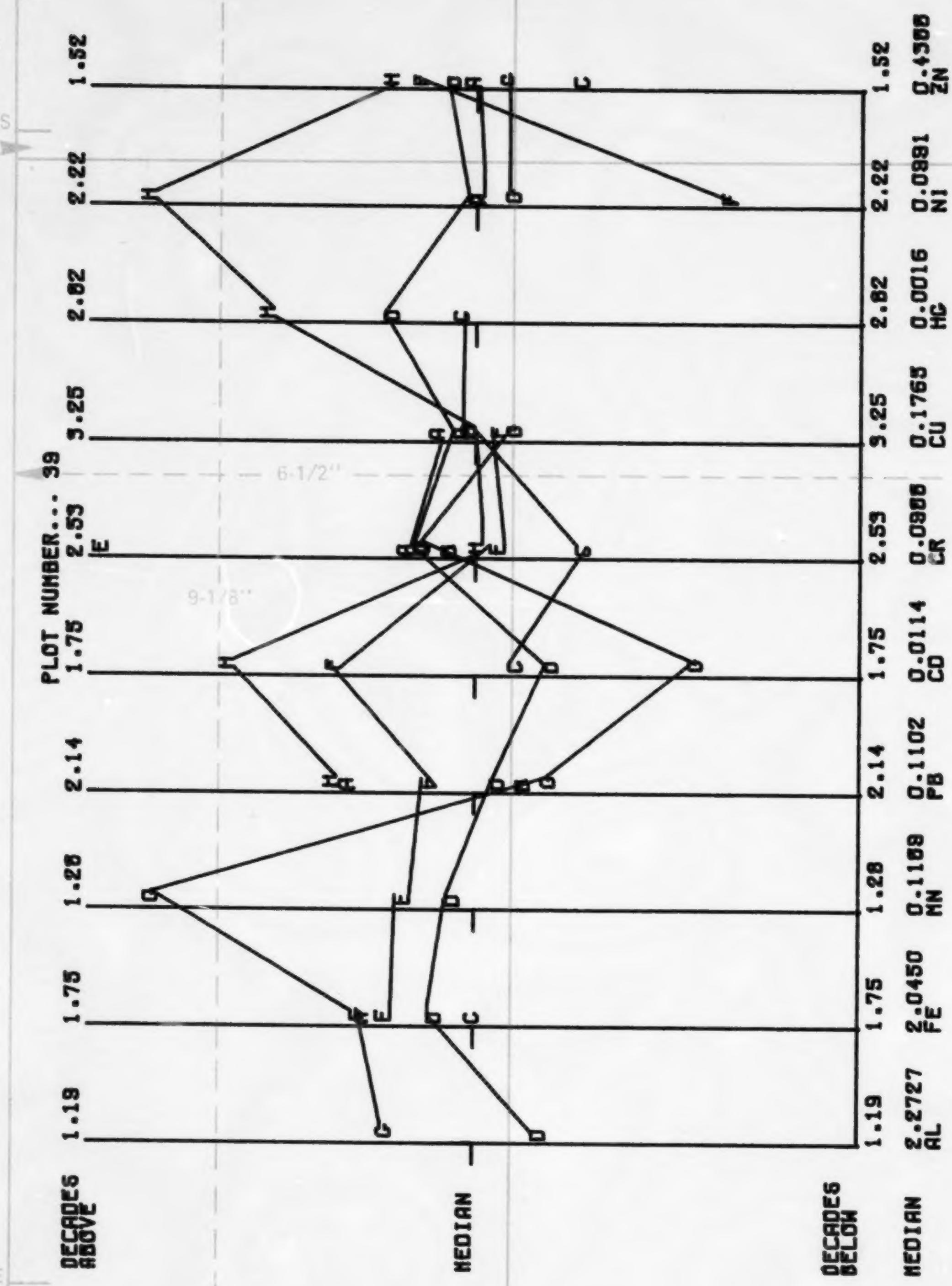

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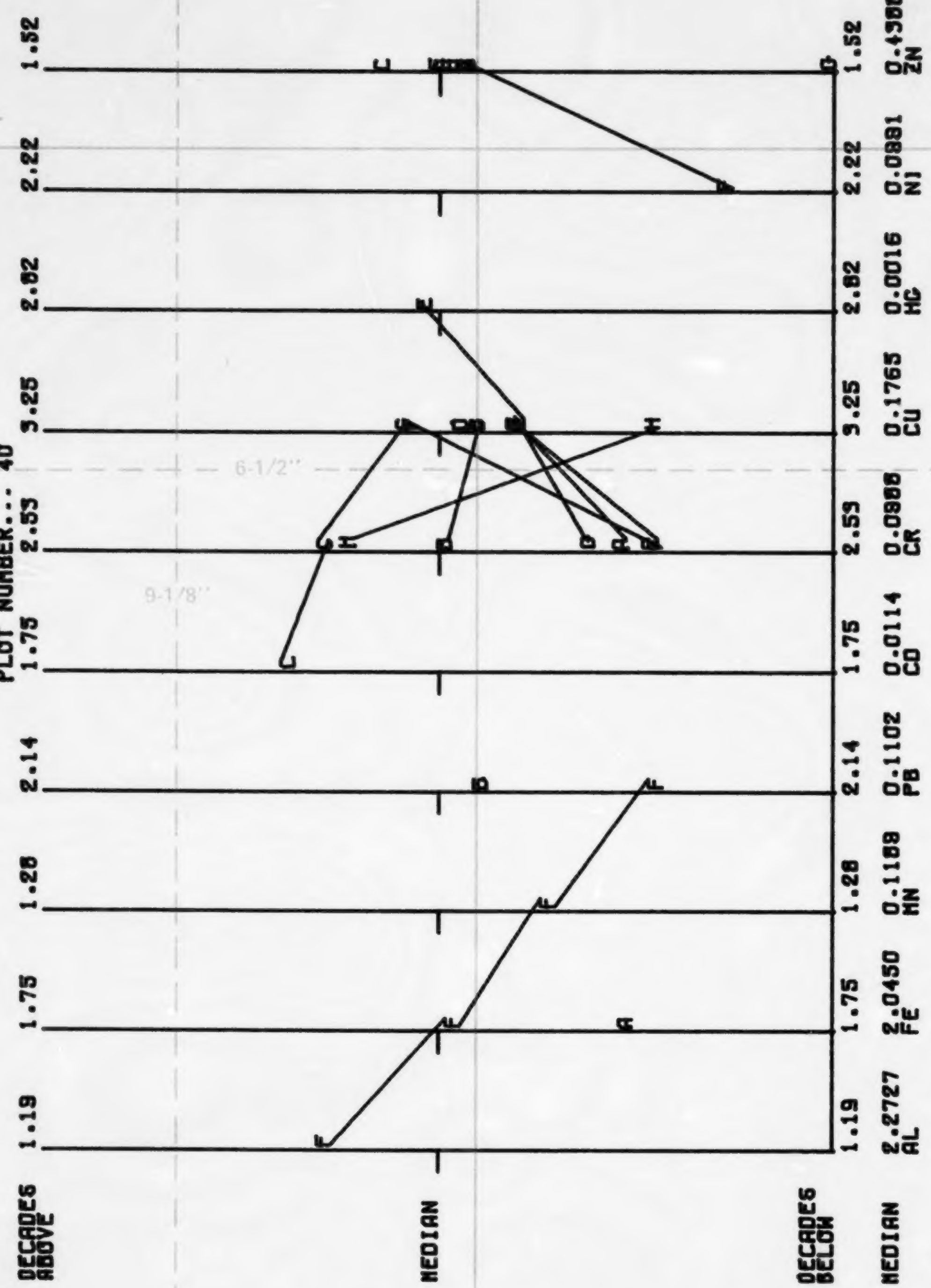

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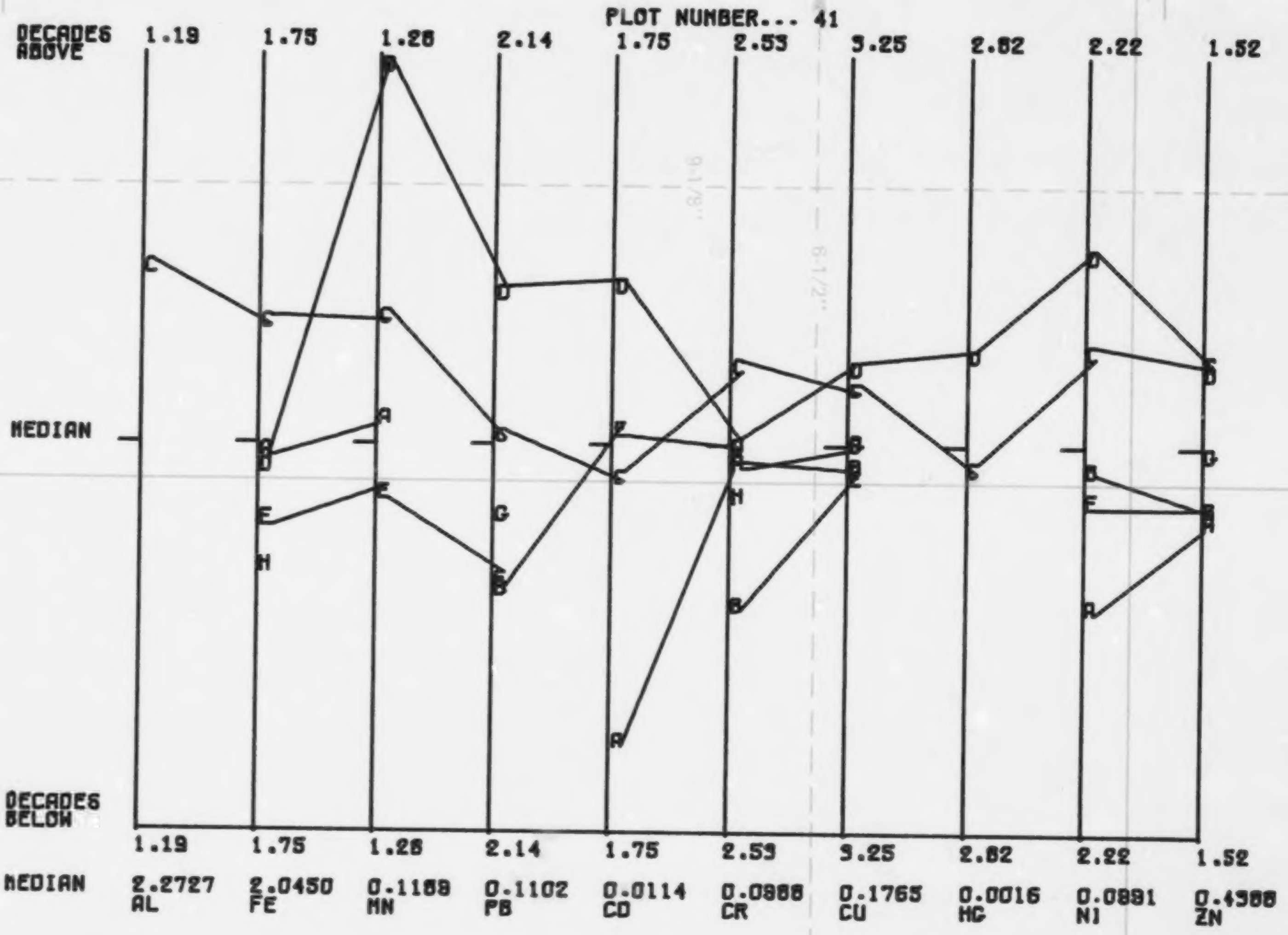

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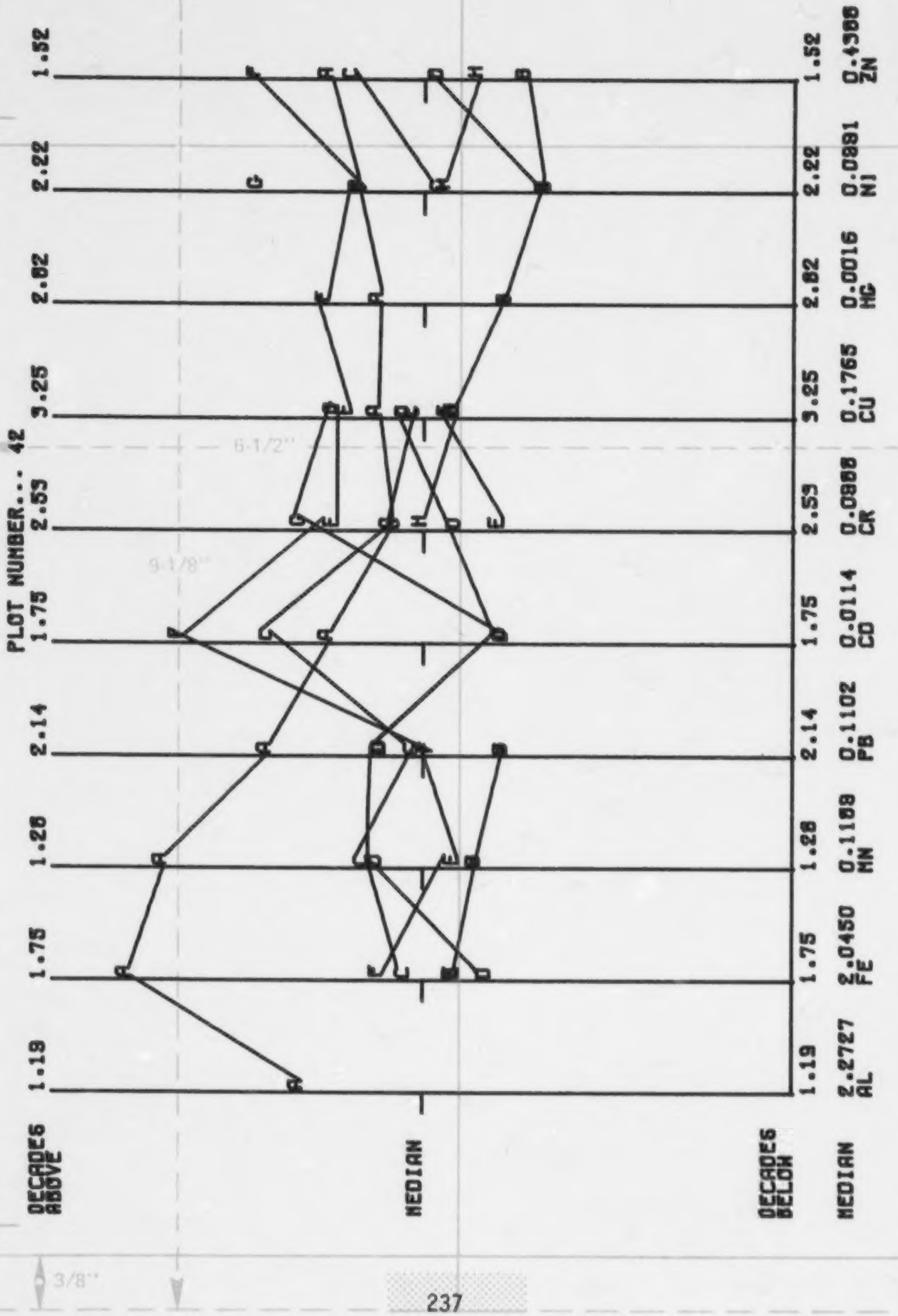

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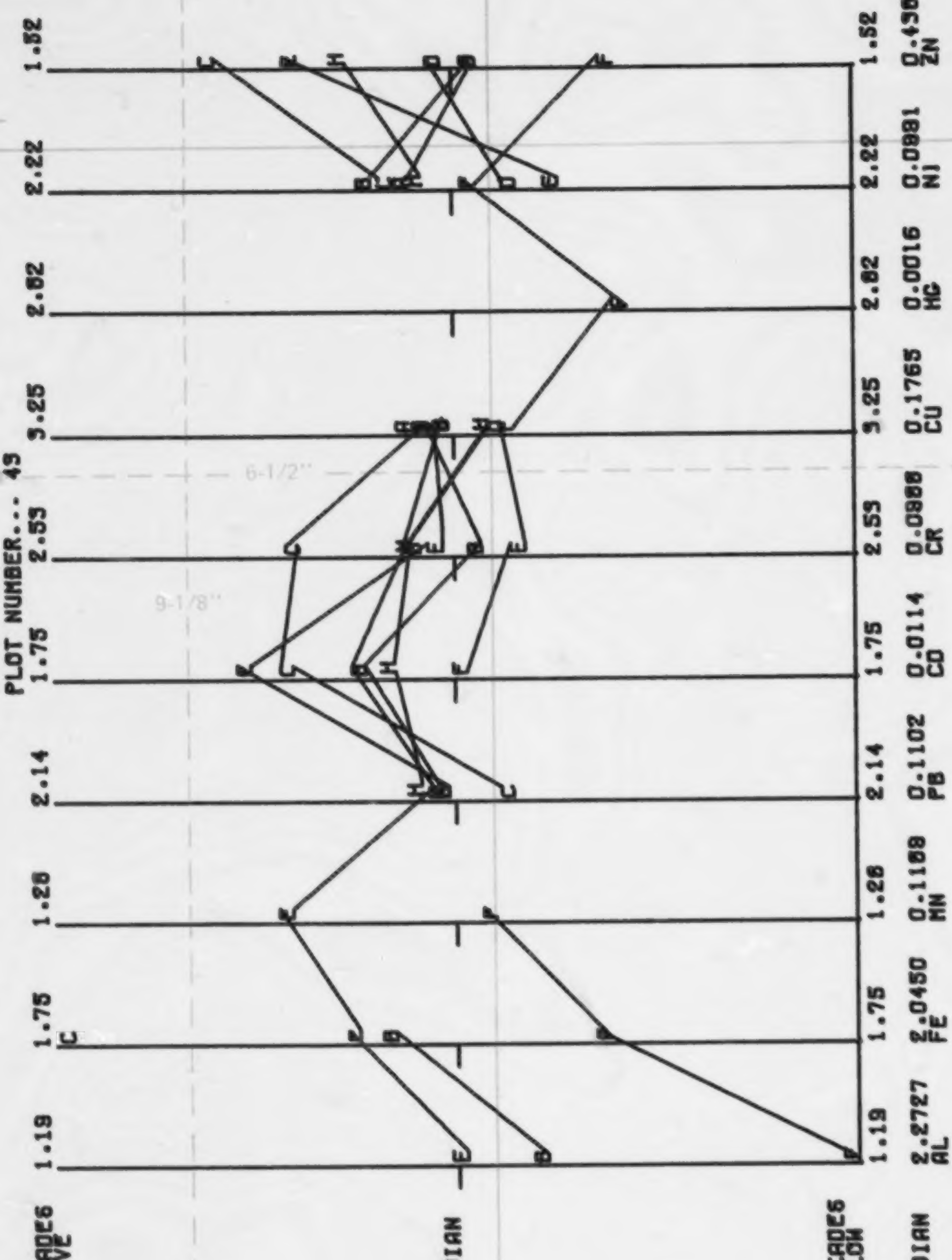

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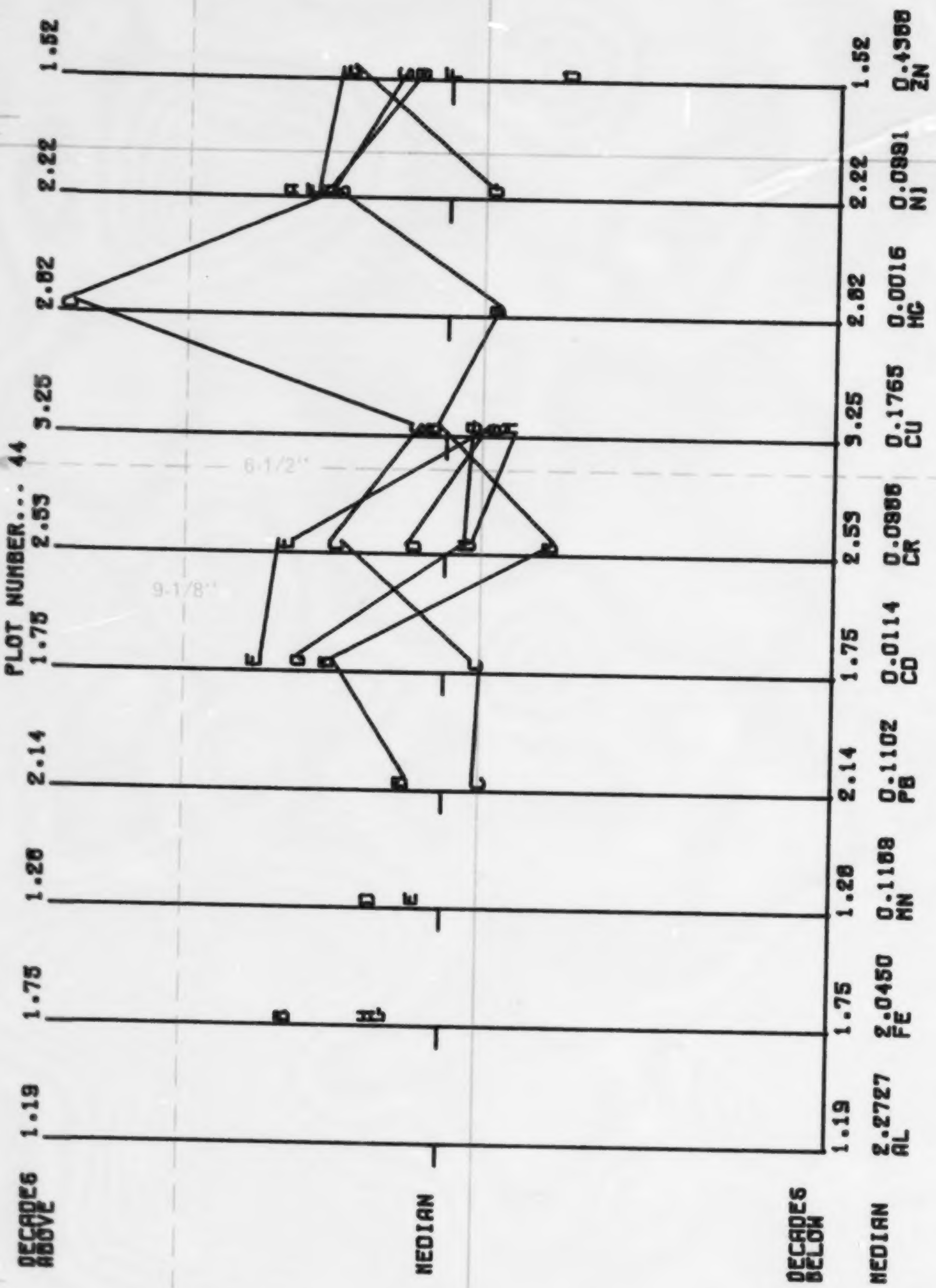

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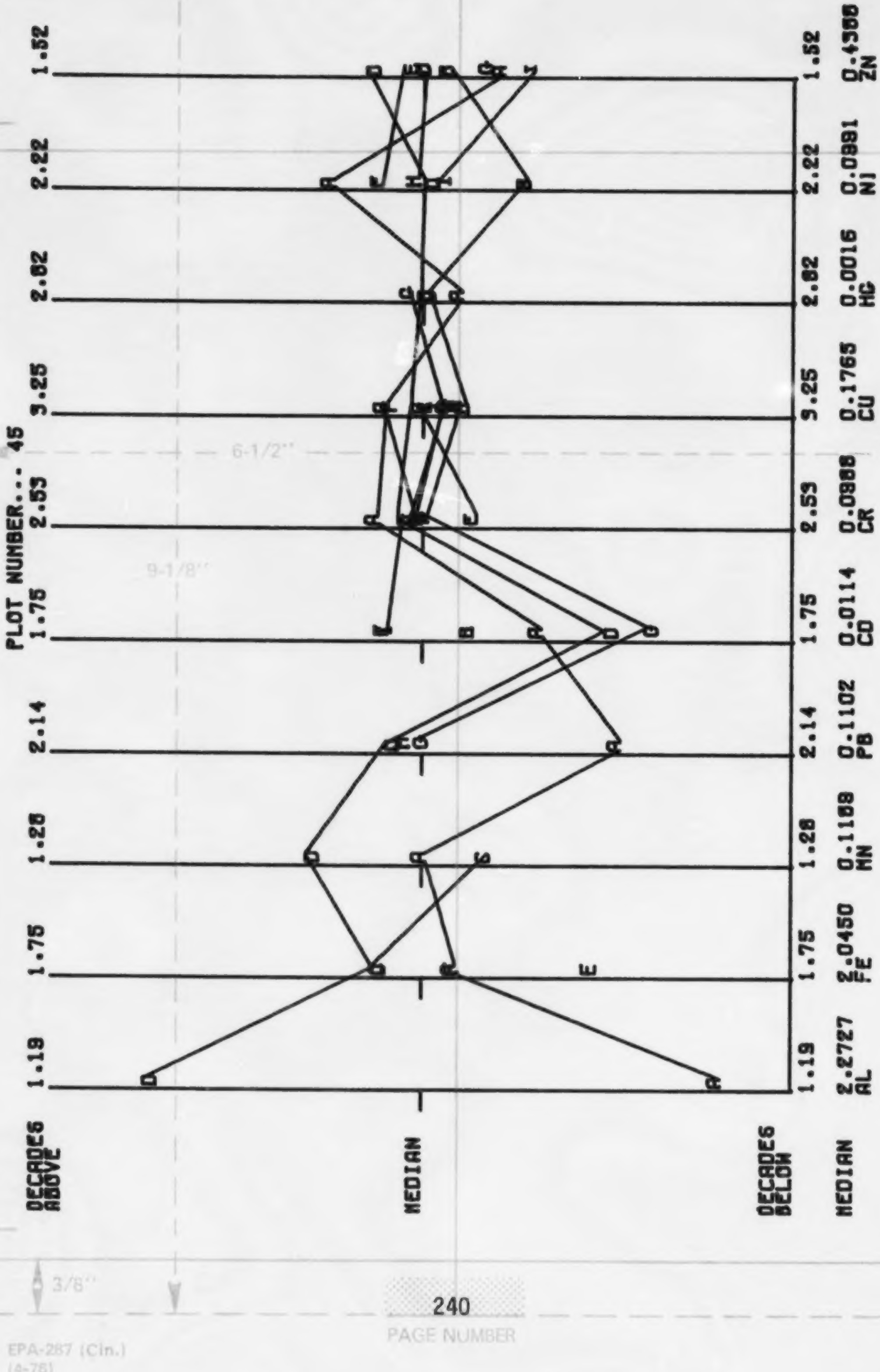

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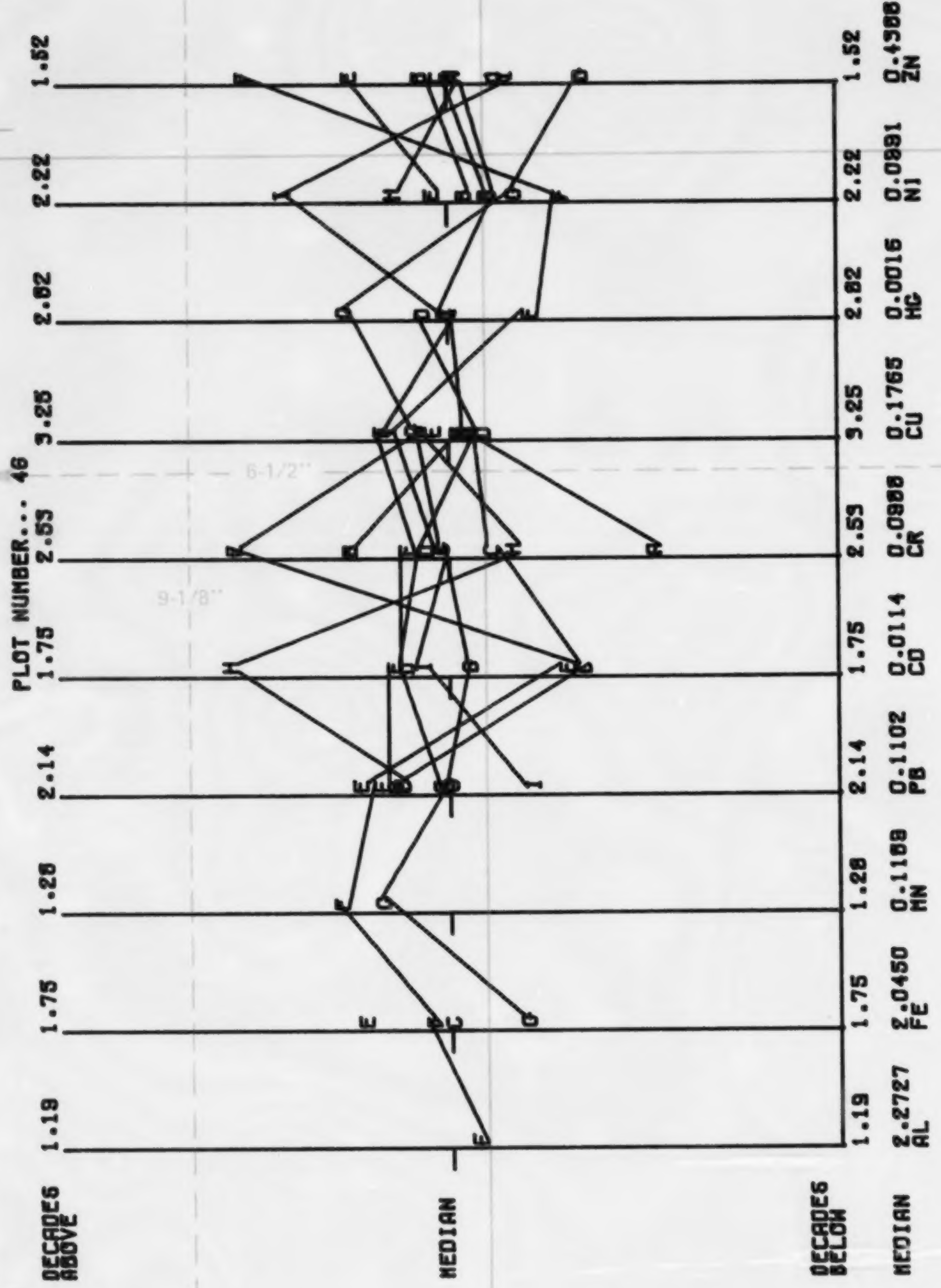

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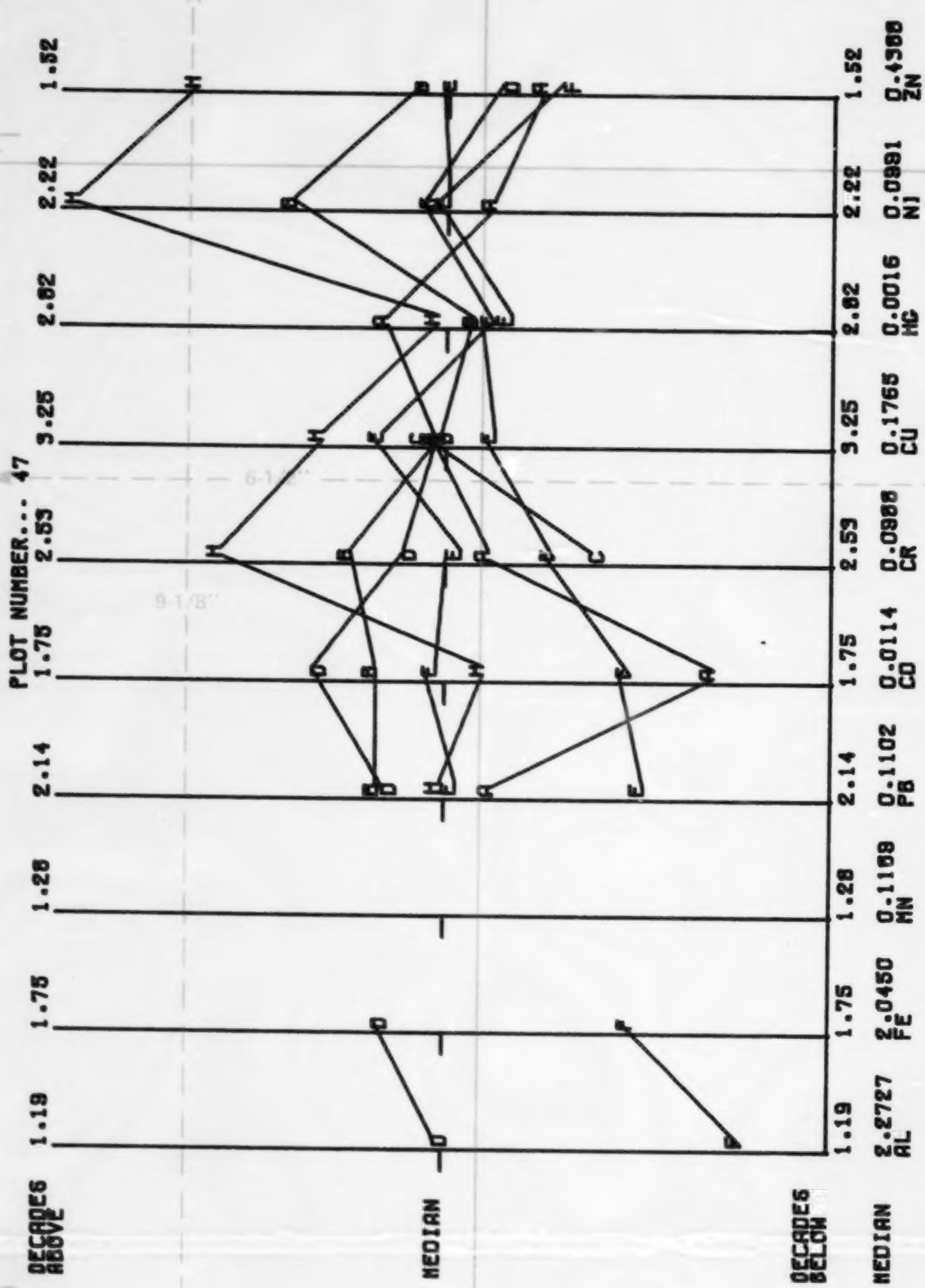

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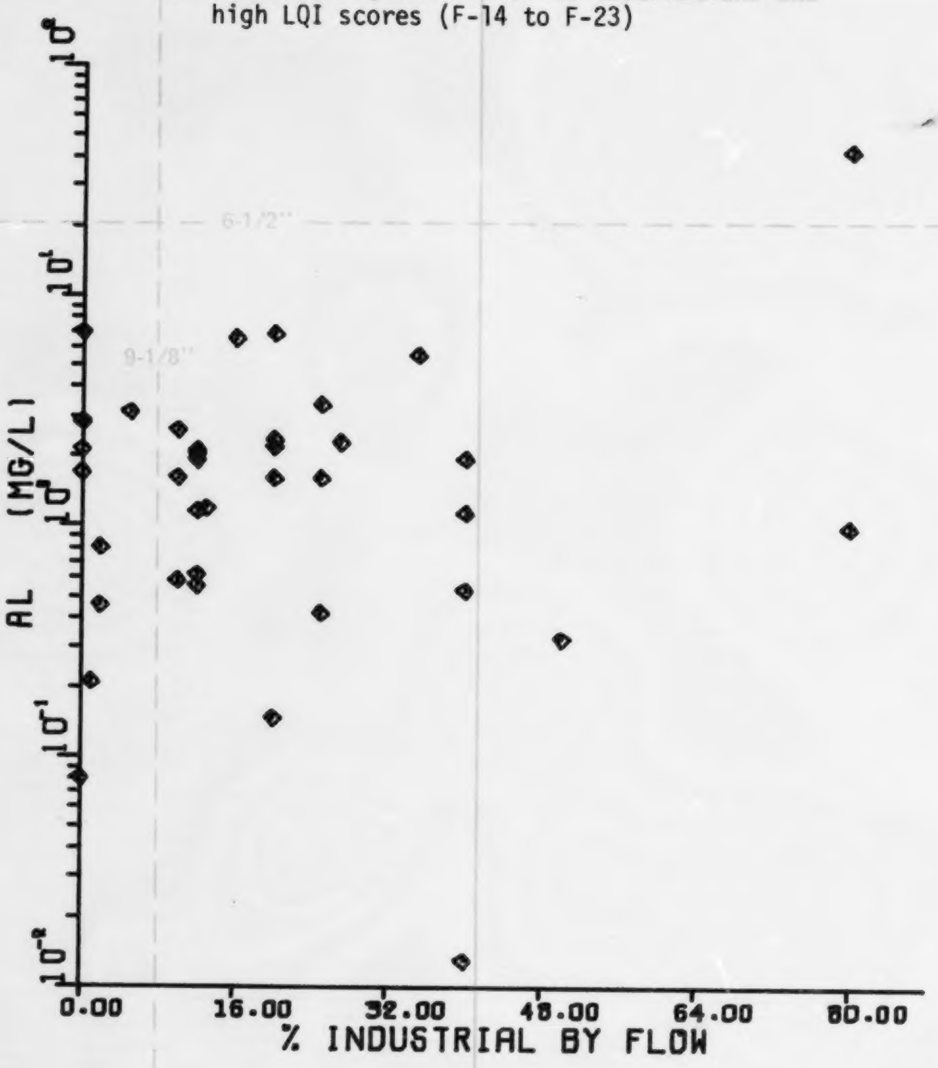
APPENDIX F

PLOTS OF HEAVY METALS CONCENTRATIONS VERSUS PERCENT INDUSTRIAL FLOW REPORTED

1. Unedited data (Figures F-1 to F-13)
2. Edited data, minimum of 25 observations and high LQI scores (F-14 to F-23)



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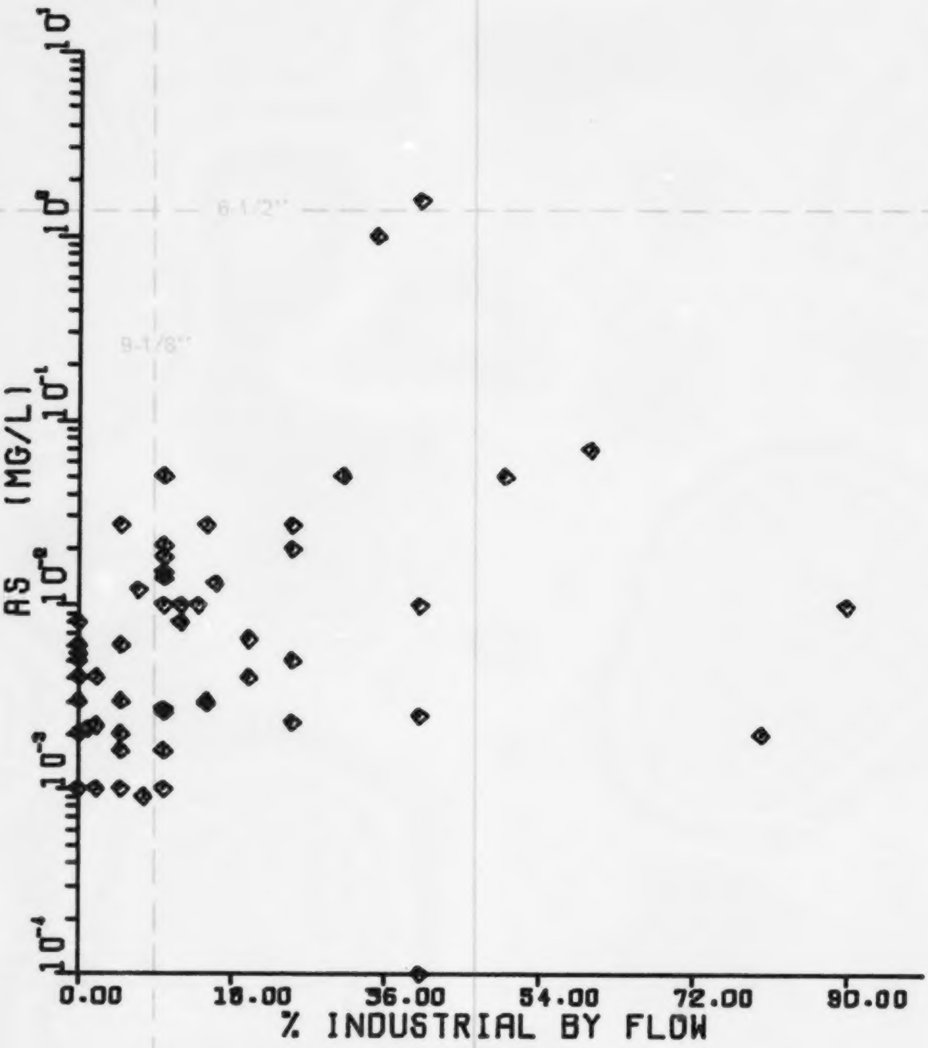

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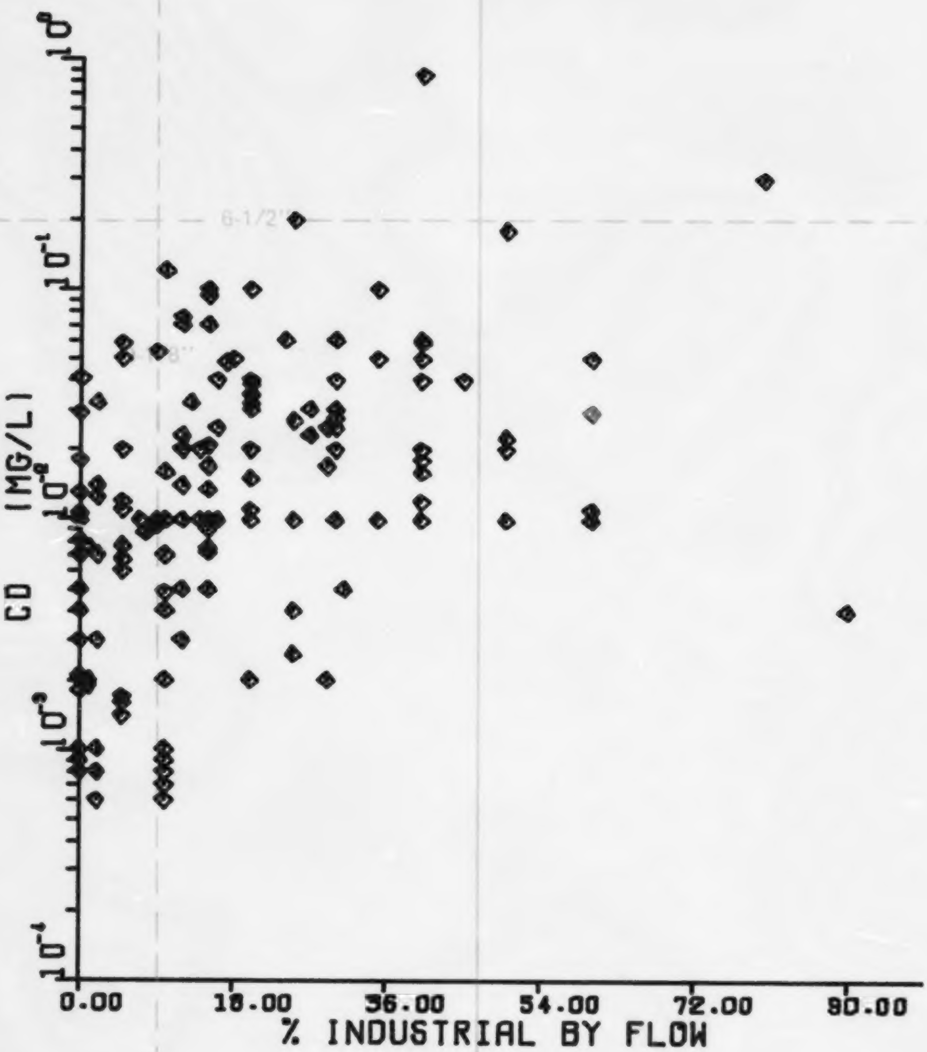

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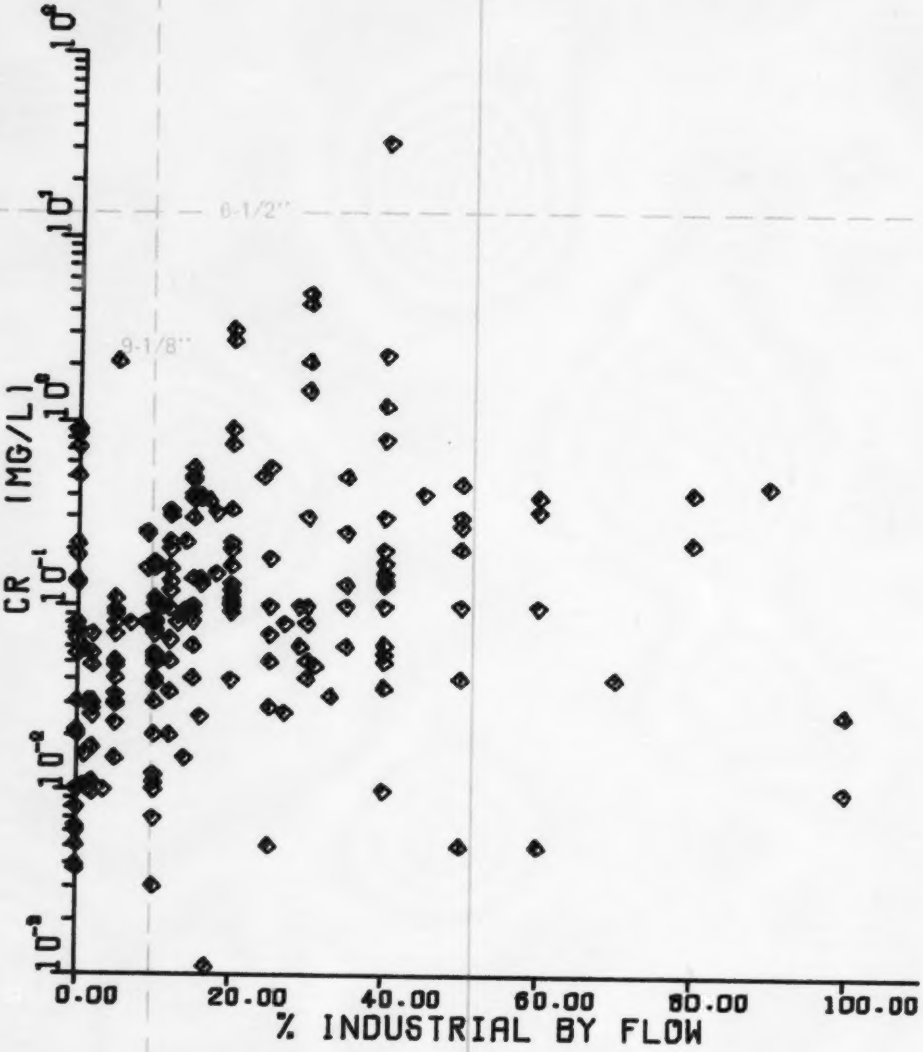

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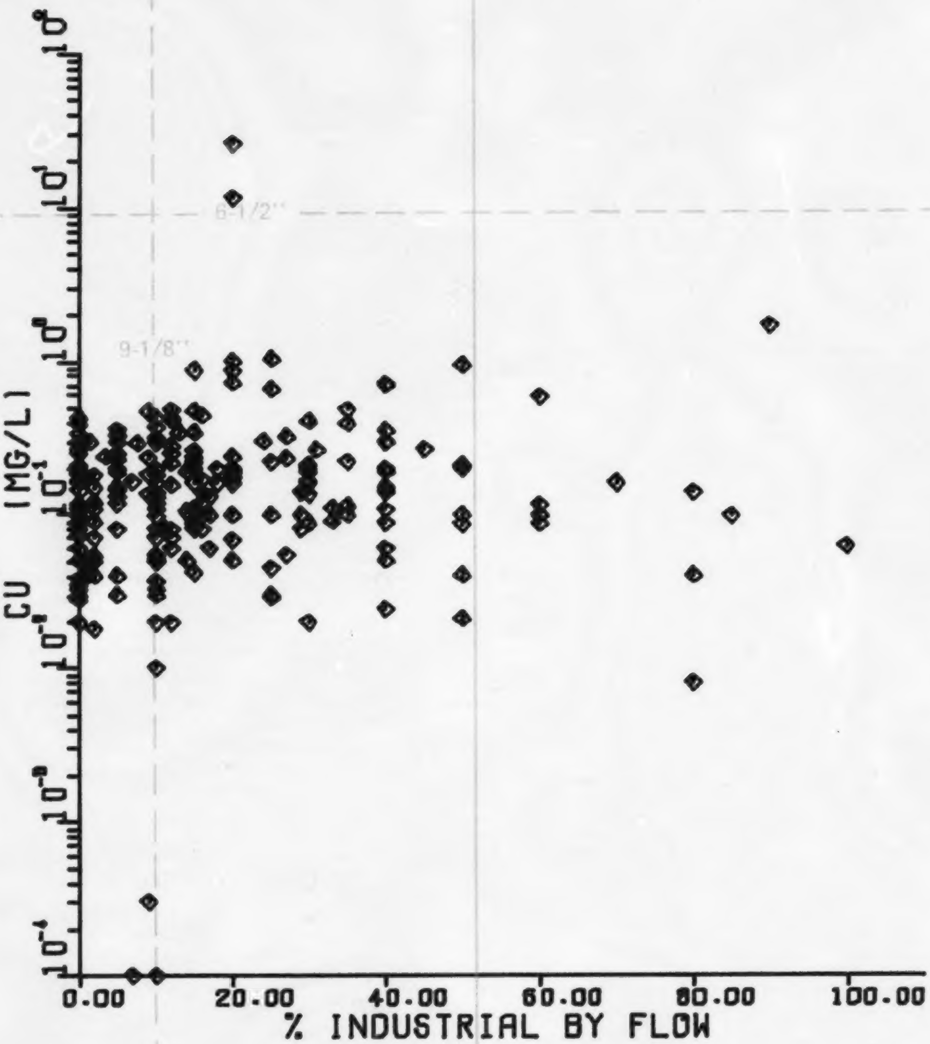

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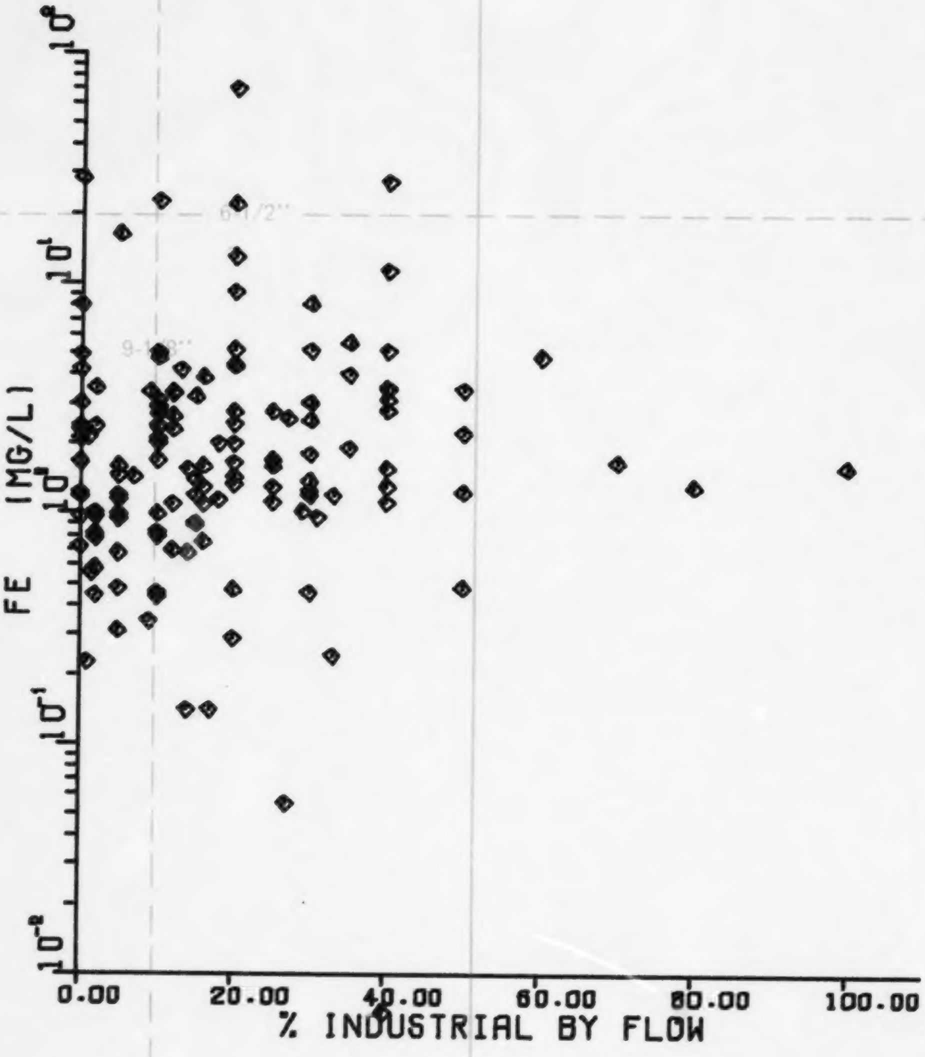

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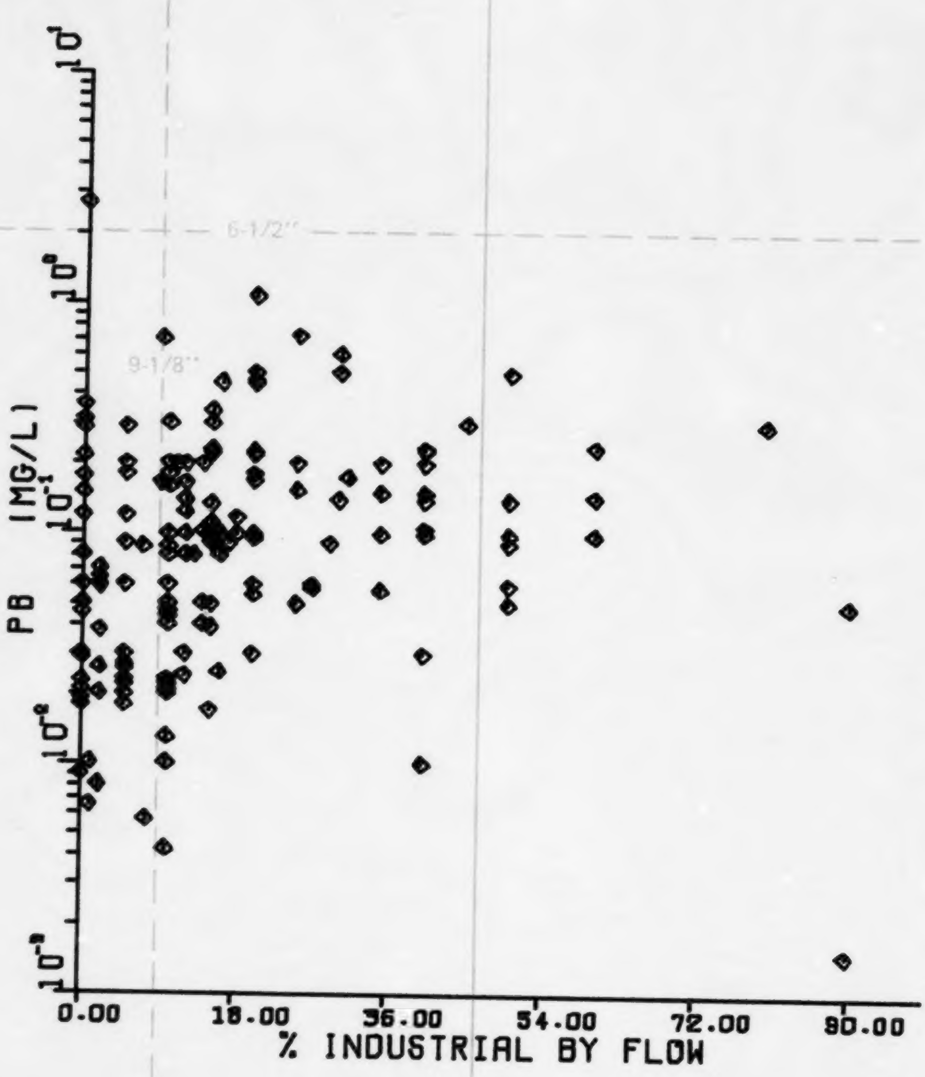

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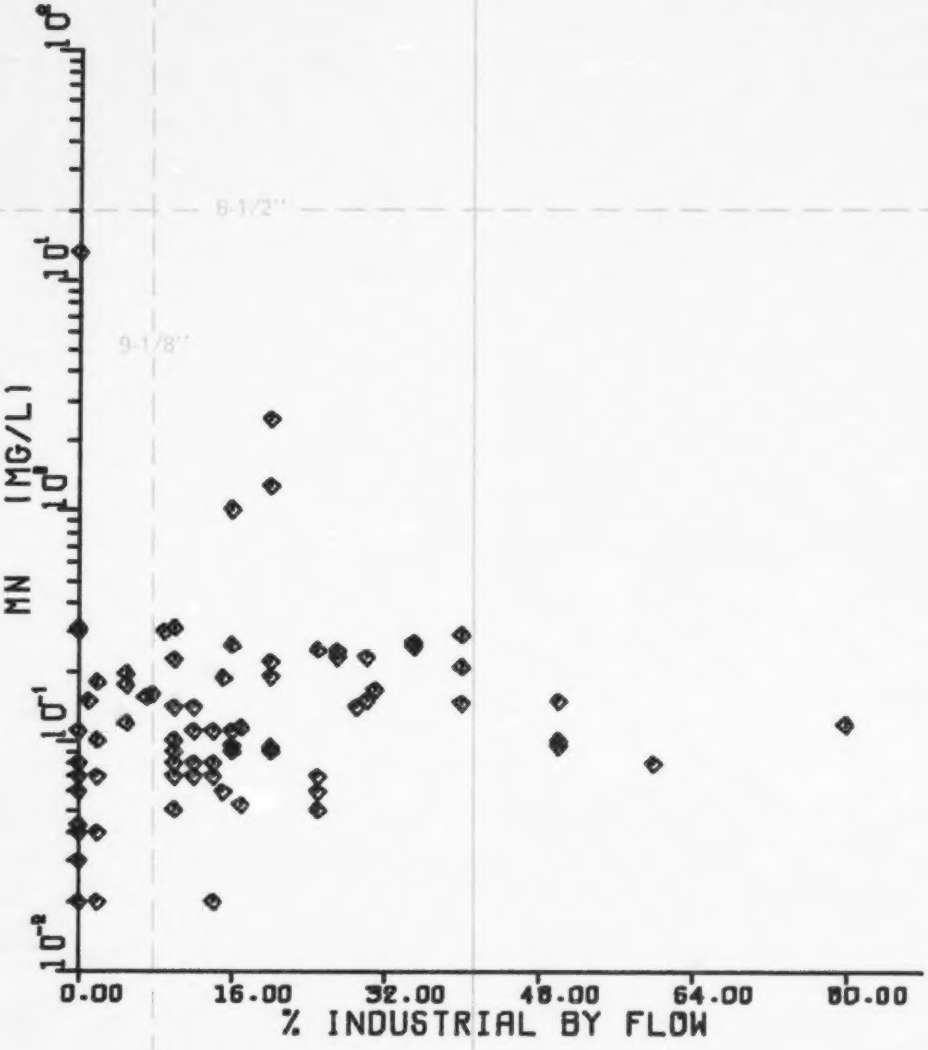

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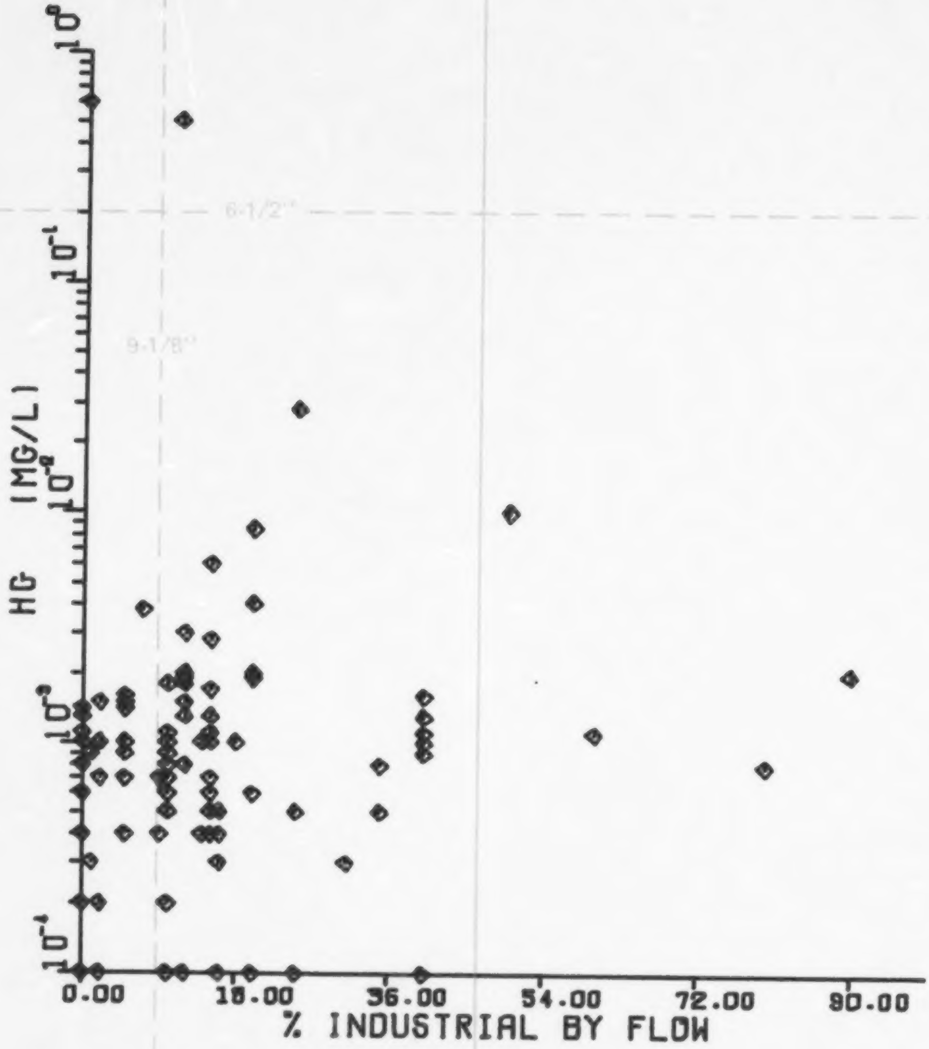

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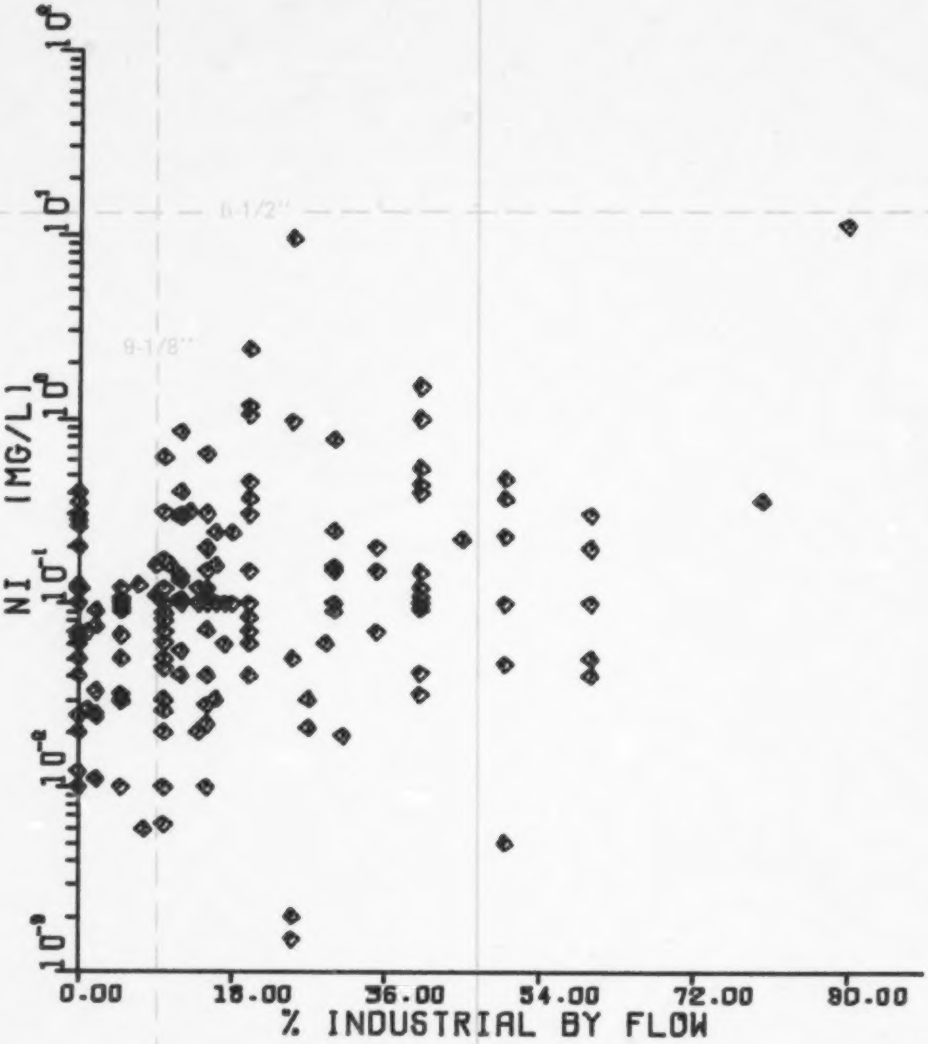

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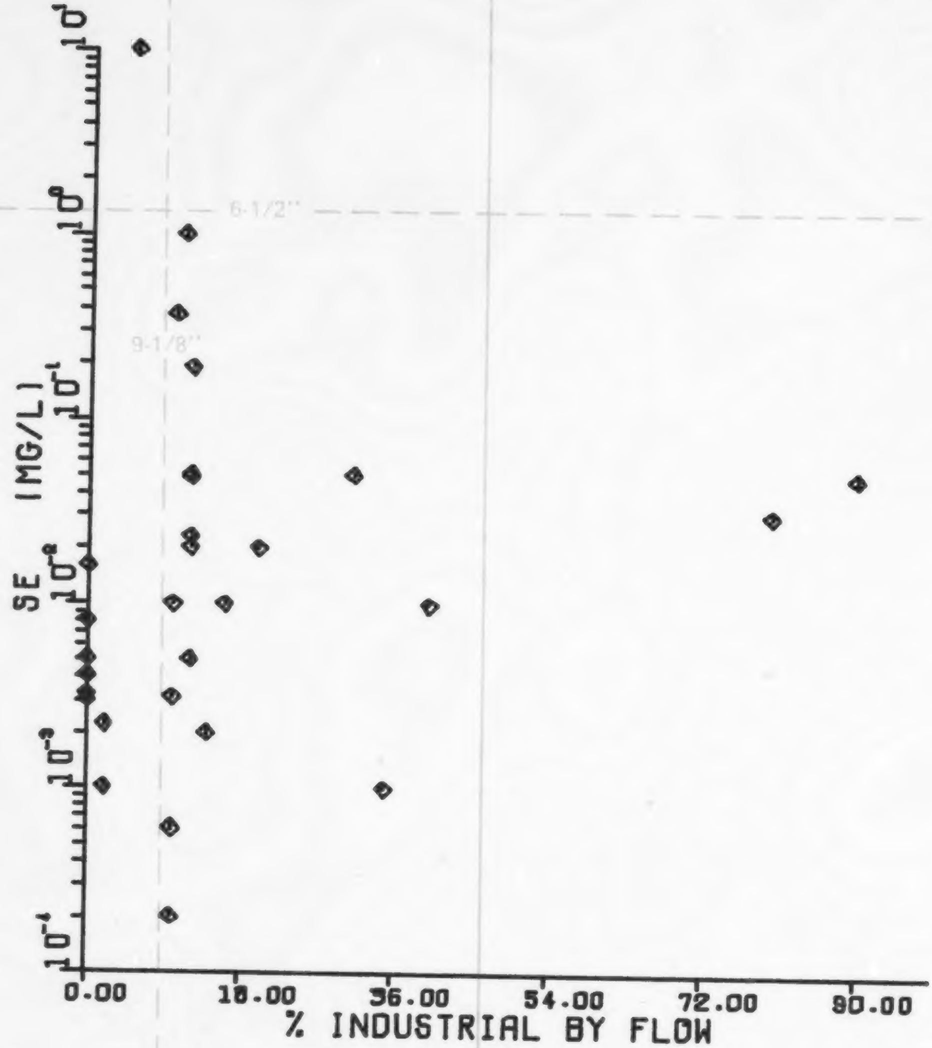

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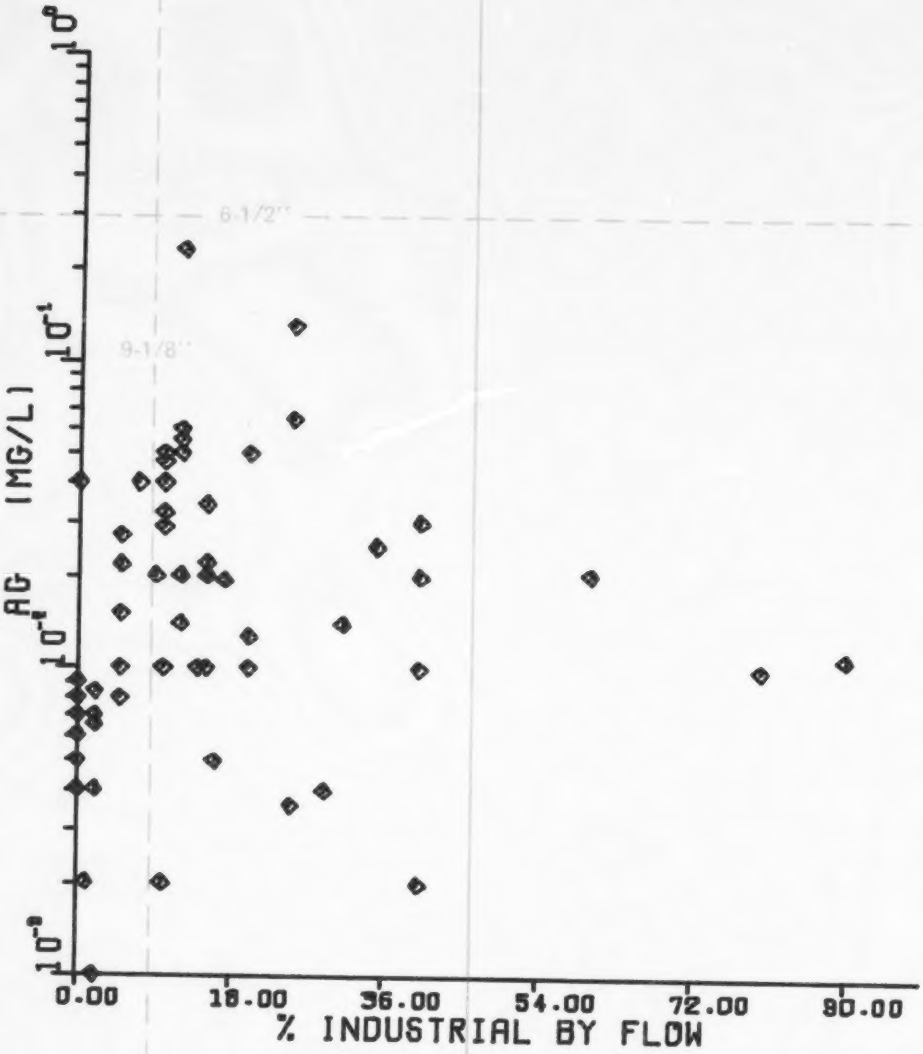

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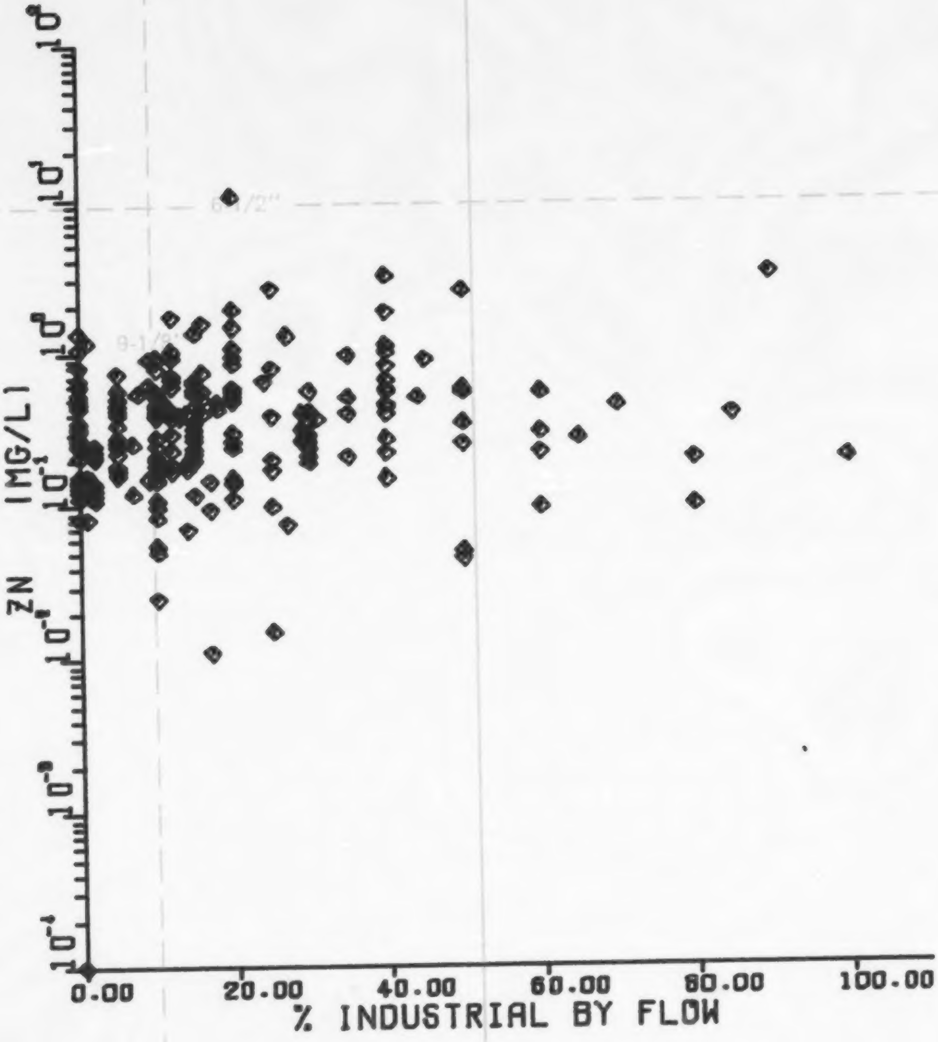

Figure F-13.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE
6-1/2"
9-1/8"

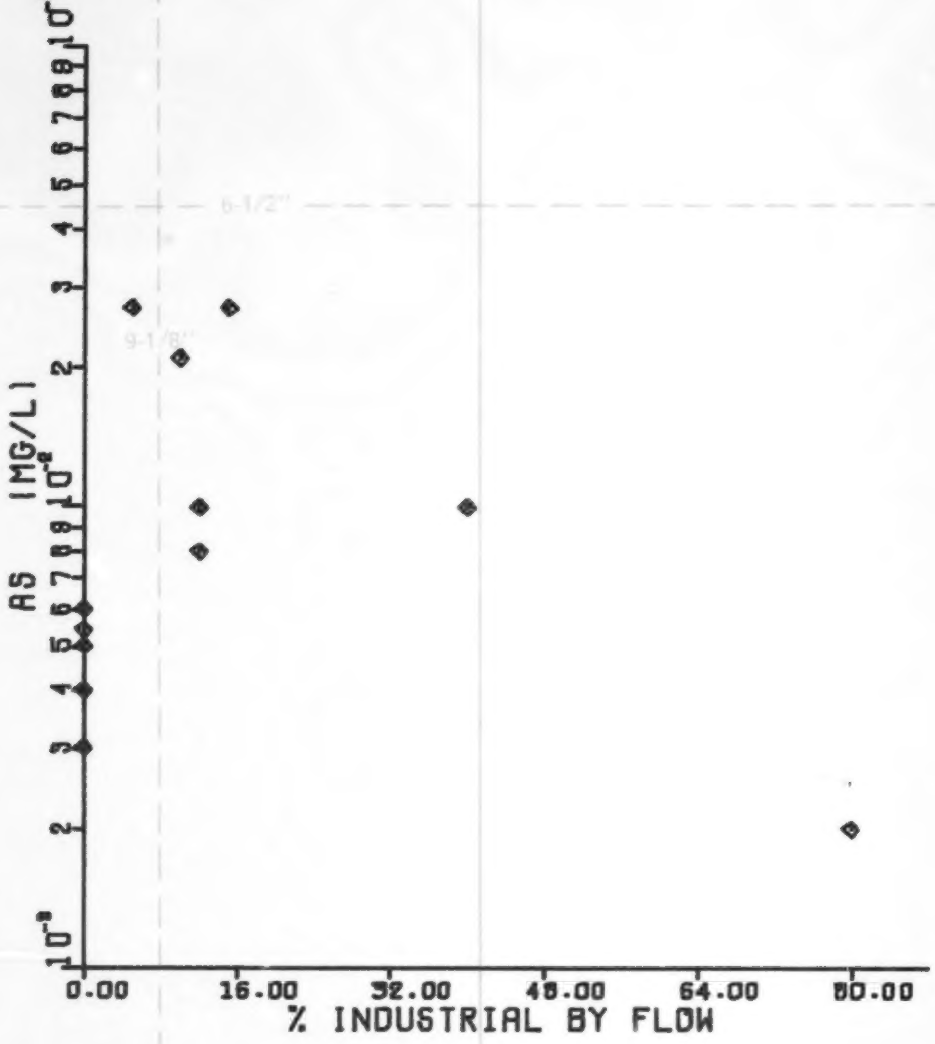

Figure F-14.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
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CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2''
9-1/8''
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8''

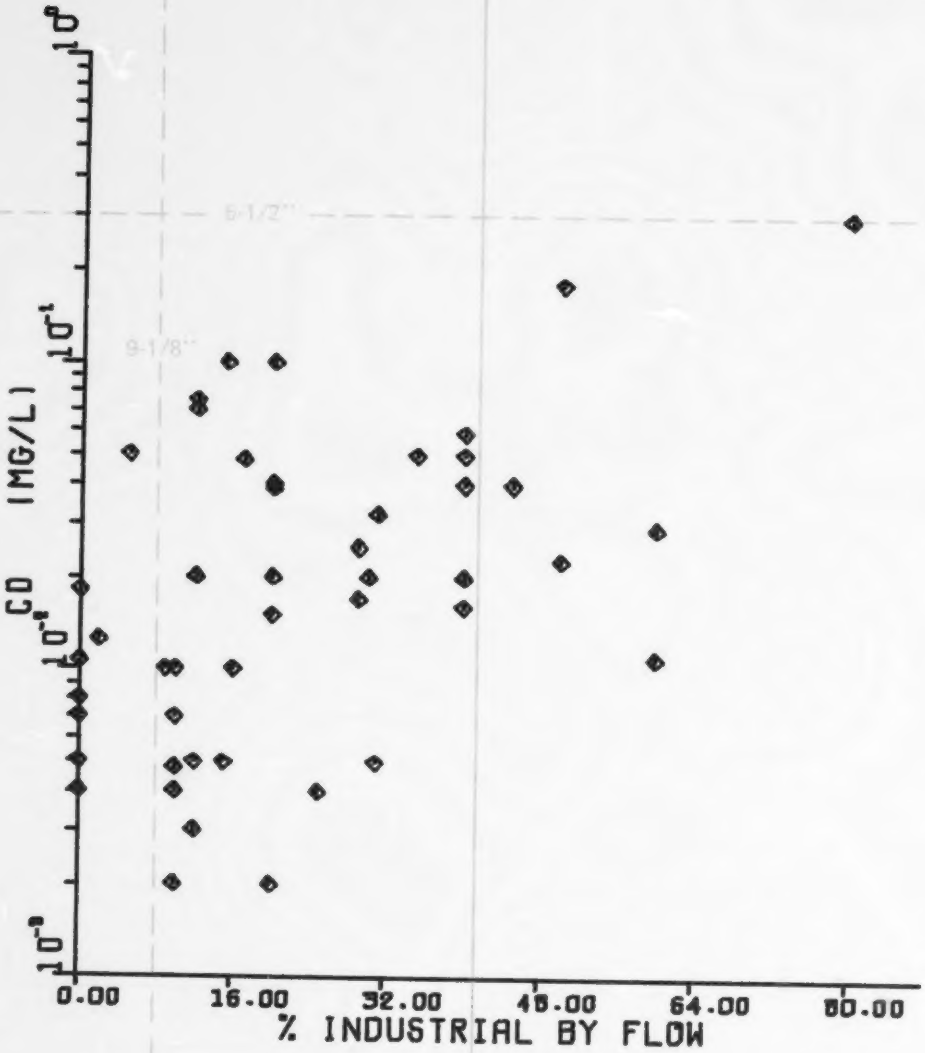

Figure F-15.

EPA-287 (Cin.)
(4-76)

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9-1/8"

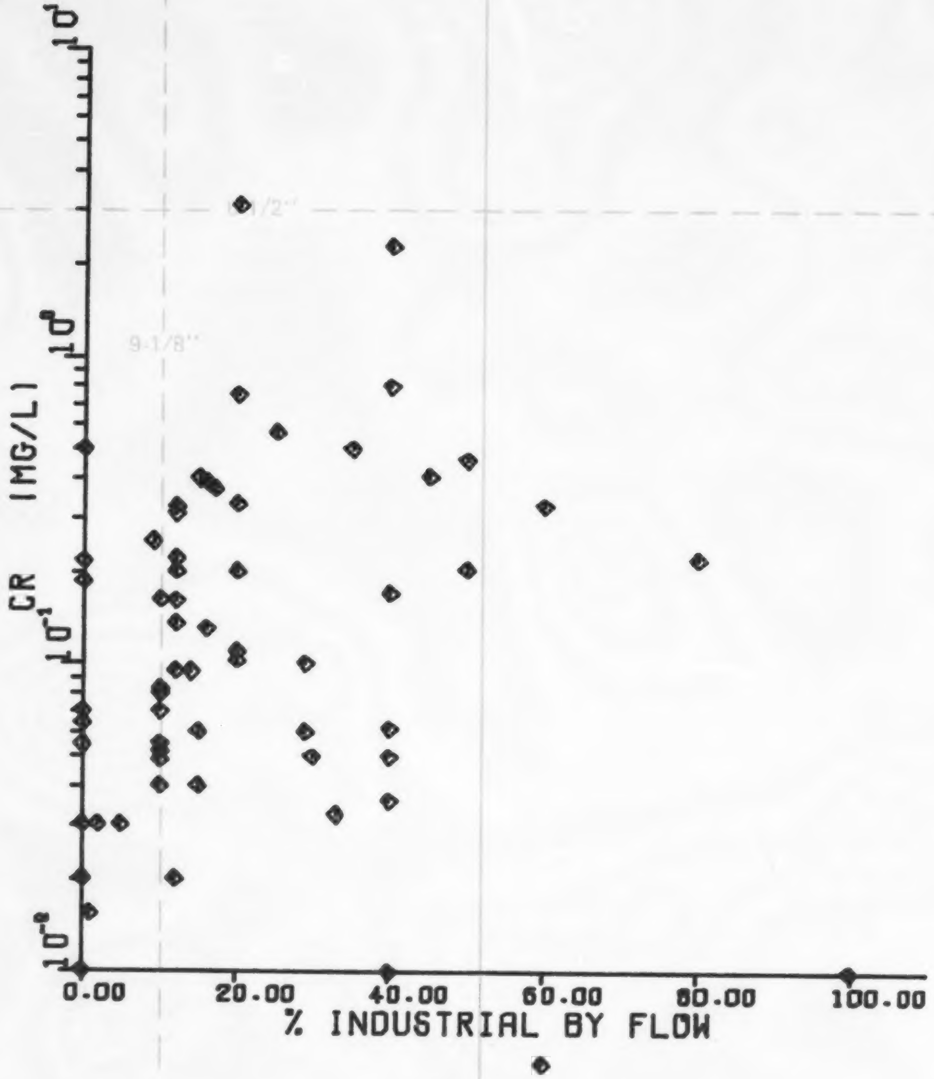

Figure F-16.

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3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
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CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE
6-1/2"
9-1/8"

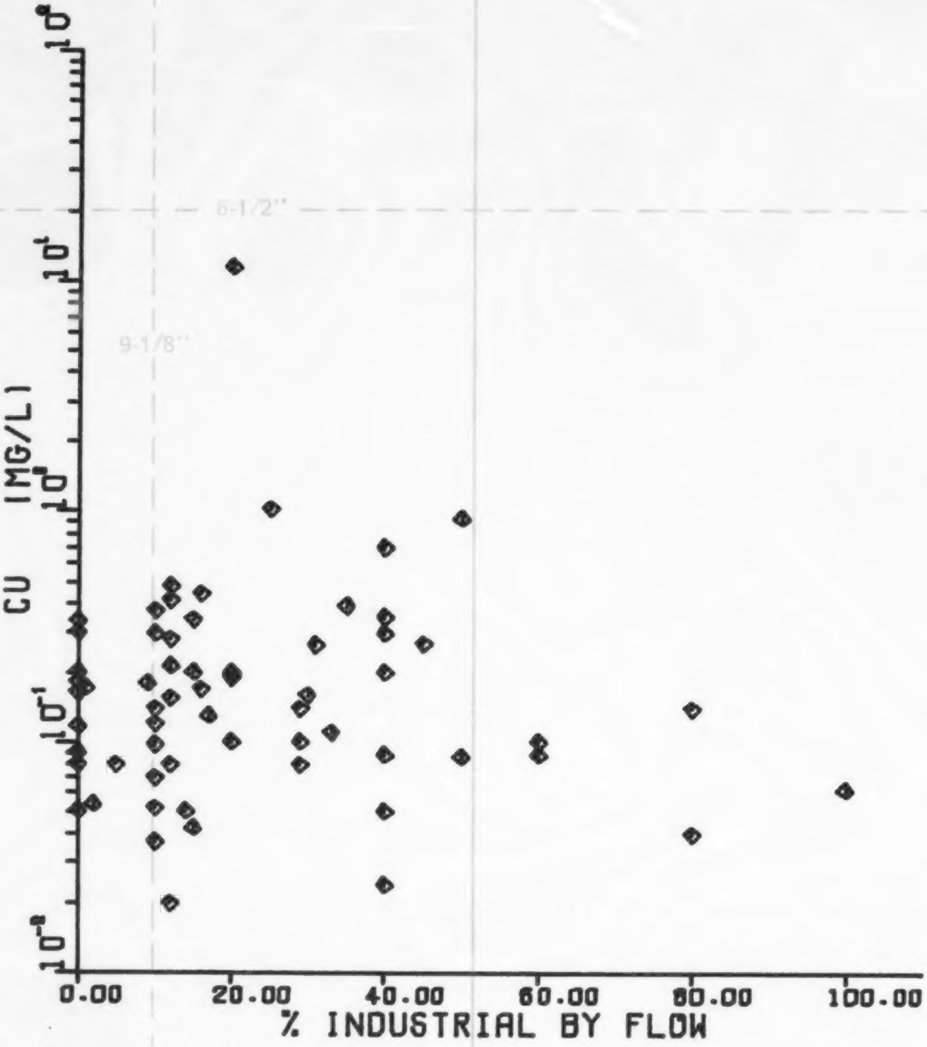

Figure F-17.

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3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
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CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
9-1/8"

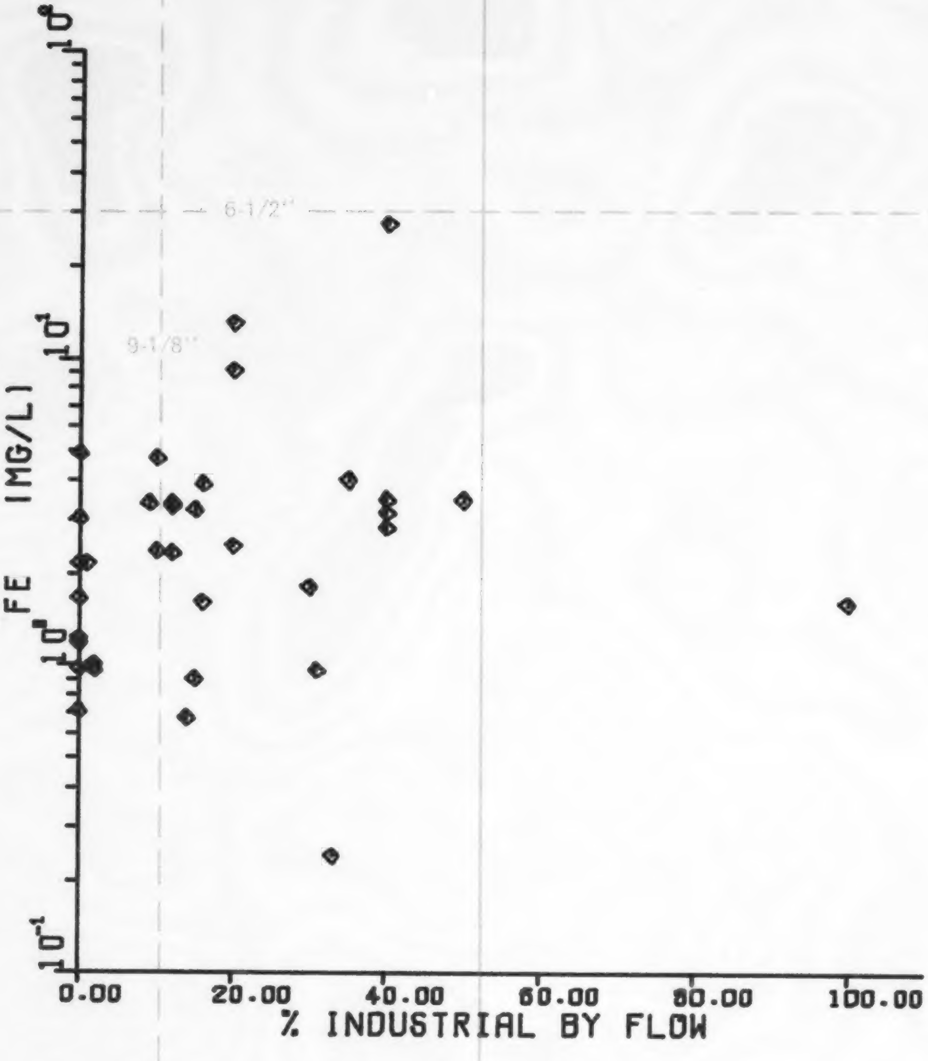

Figure F-18.

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BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
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CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/8"
9-1/8"

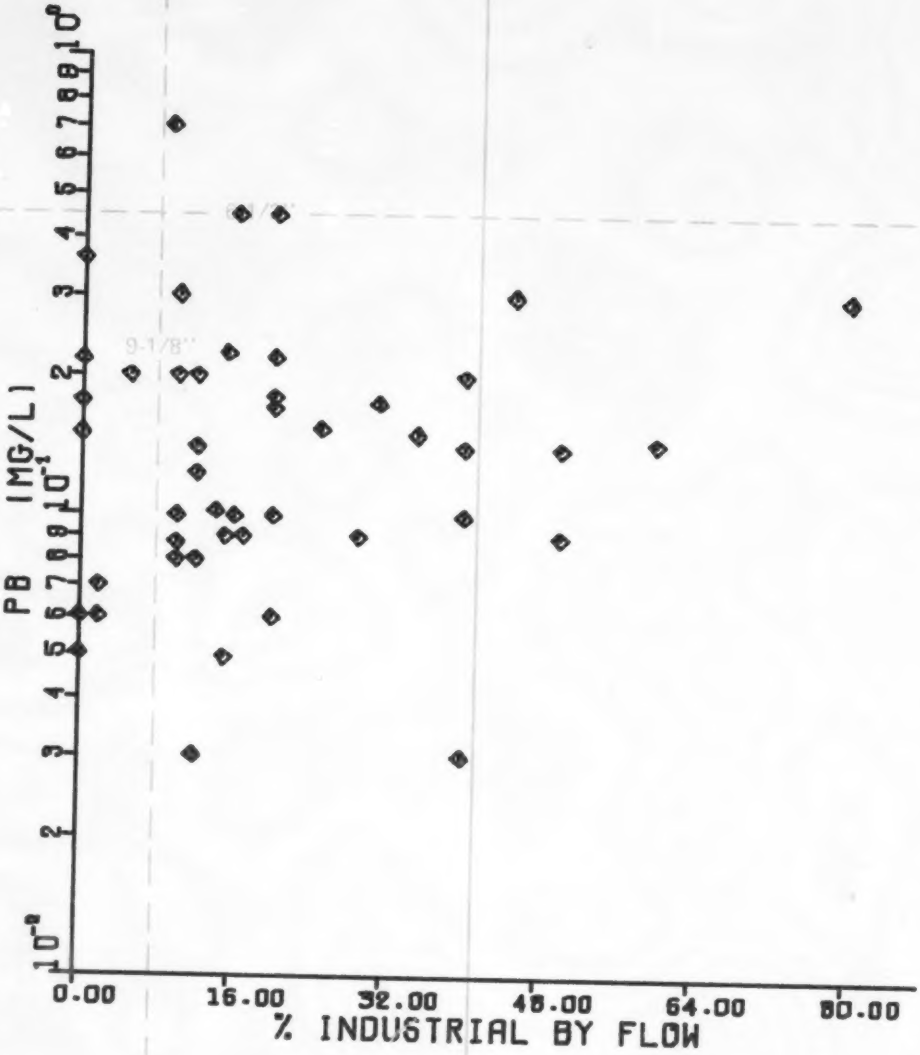

Figure F-19.

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BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

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CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
9-1/8"

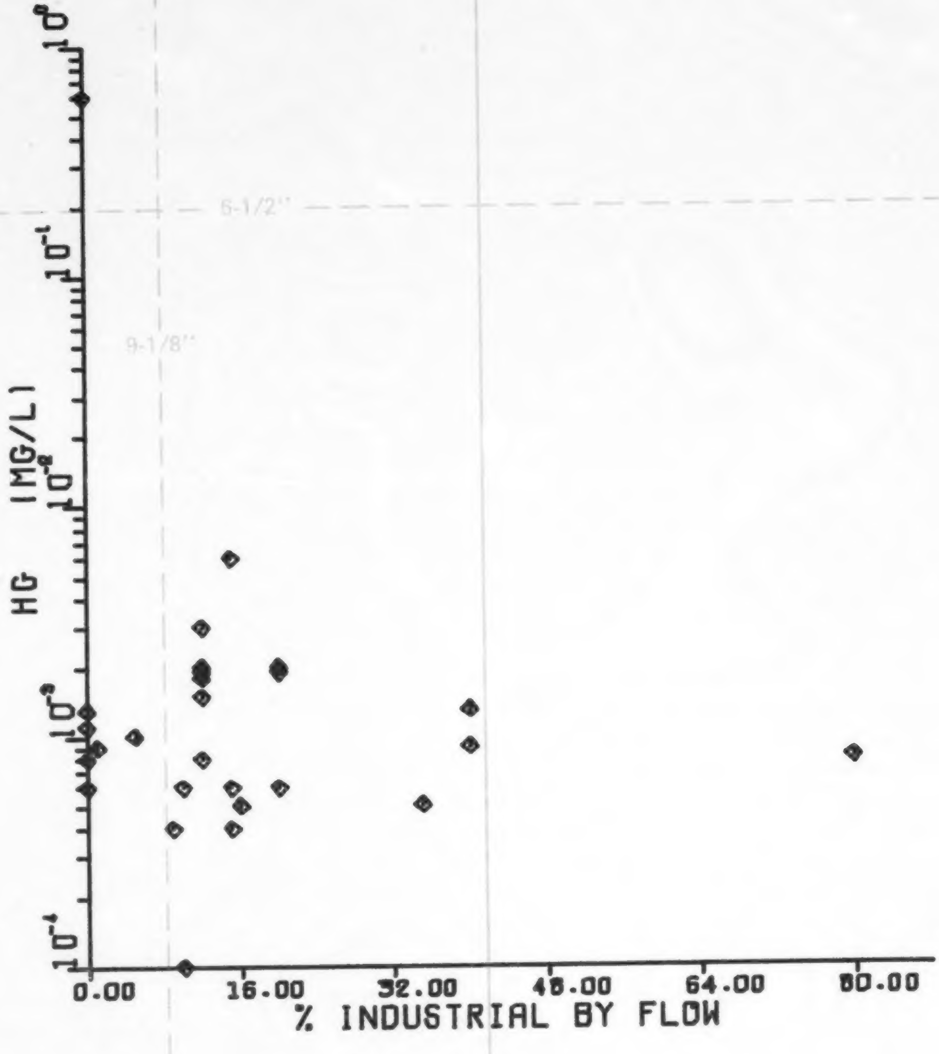

Figure F-20.

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3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
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CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2''
9-1/8''
BEGIN LAST LINE OF TEXT
3/8''
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

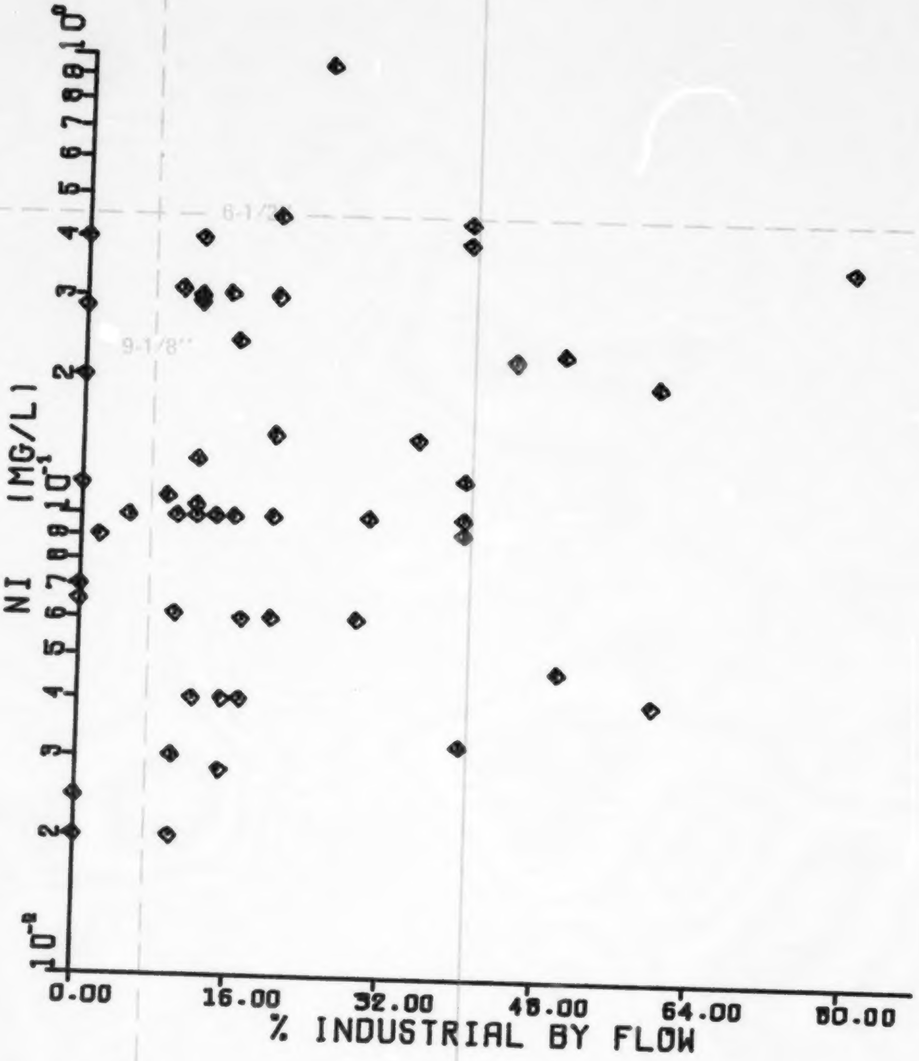

Figure F-21.

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DROPPED HEAD; BEGIN SECTIONS HERE
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6-1/2"

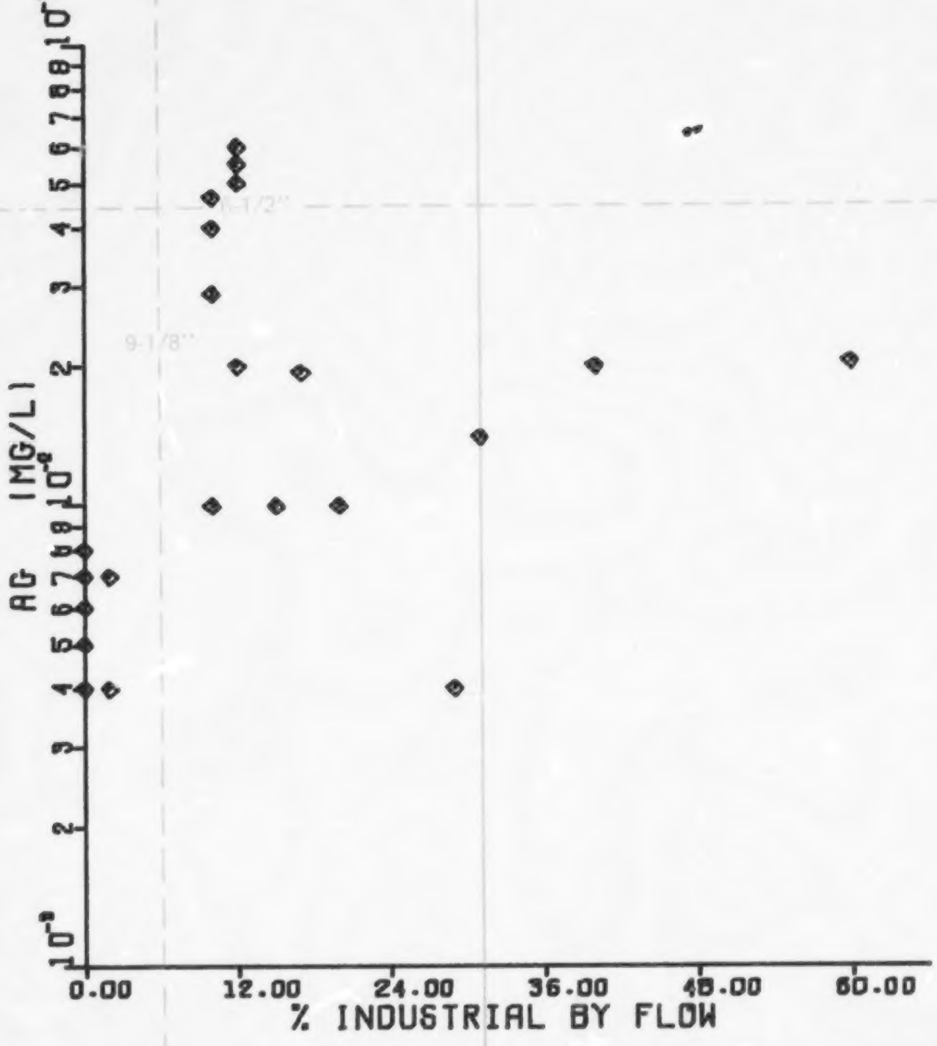

Figure F-22.

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BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

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TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

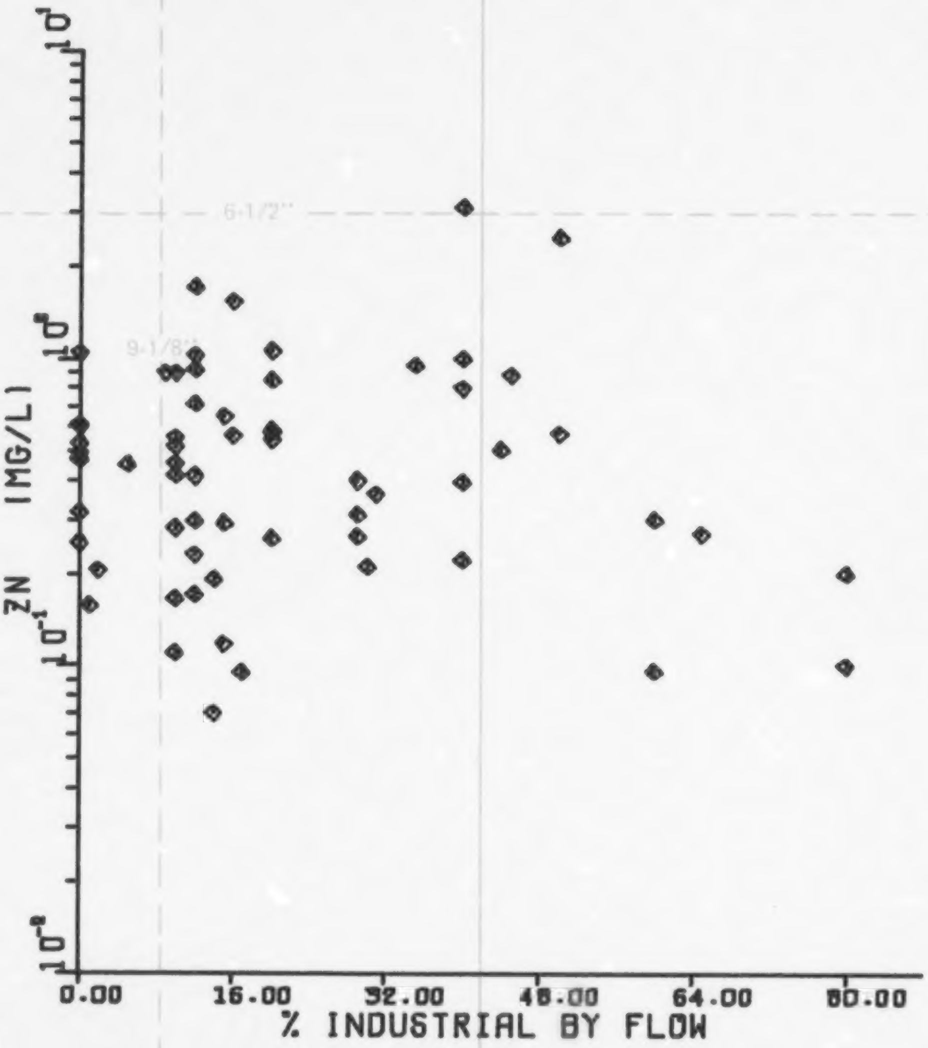

Figure F-23.

6-1/2"
9-1/8"
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BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

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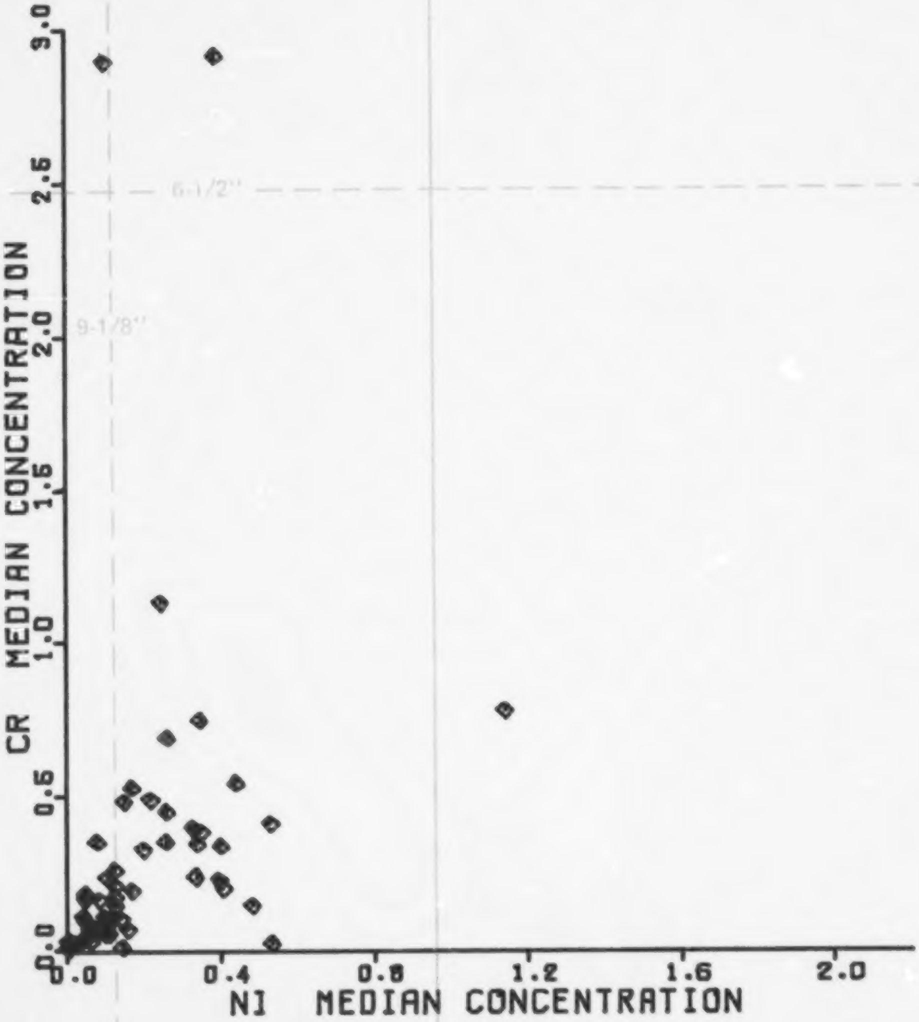
DROPPED HEAD, BEGIN SECTIONS HERE

APPENDIX G

CROSS PLOTS OF SELECTED HEAVY METALS



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9-1/8"
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BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

Figure G-1.

EPA-287 (Cin.)
(4-76)

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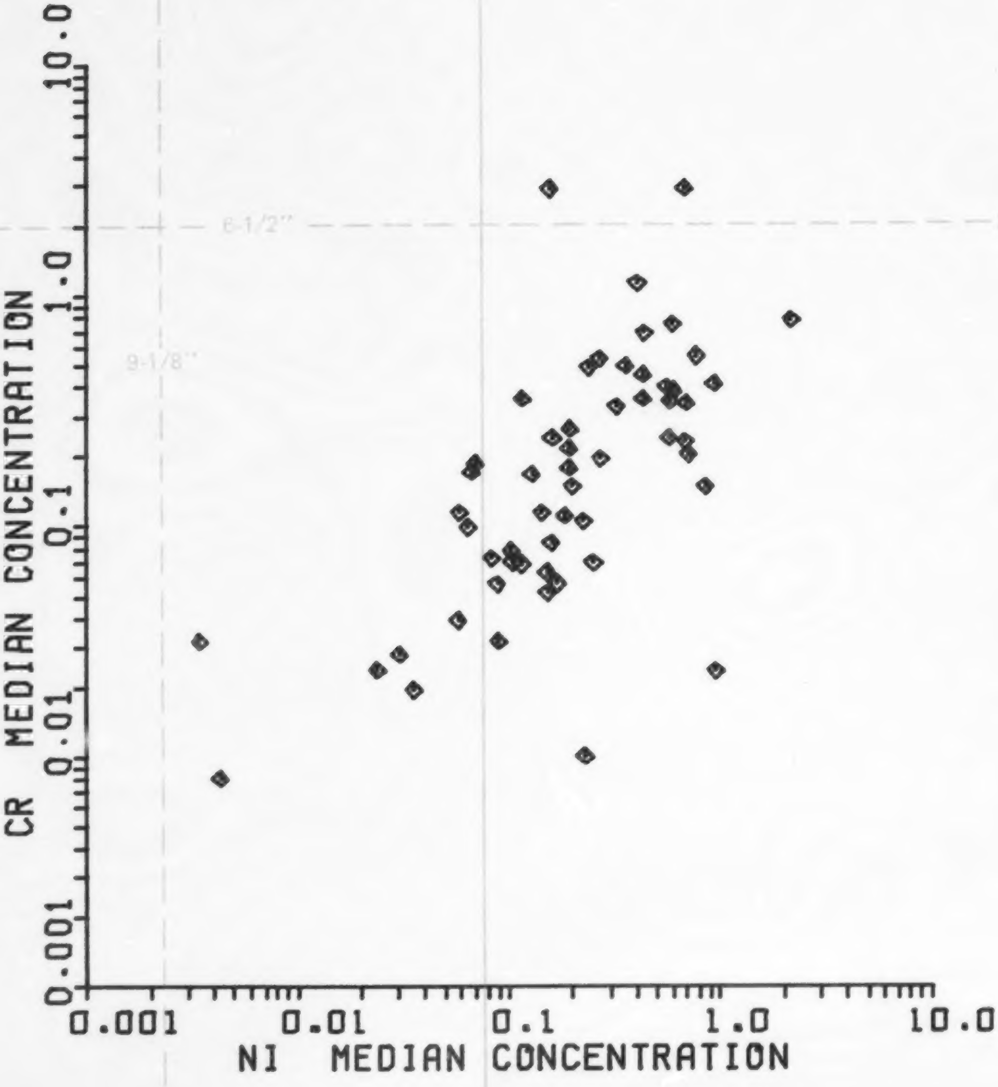

Figure G-2.

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BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8''

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

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TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

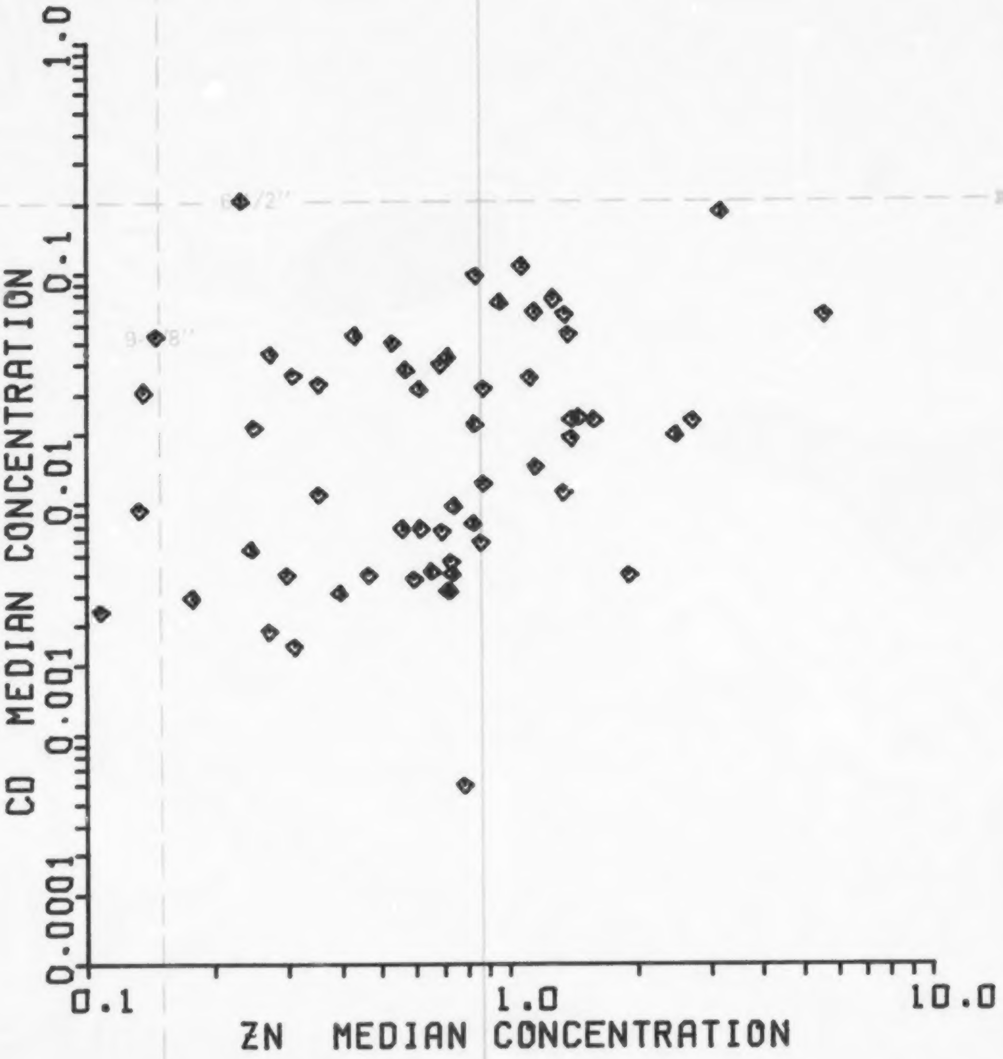

Figure G-3.

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BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8''

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

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TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE
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9-1/8"

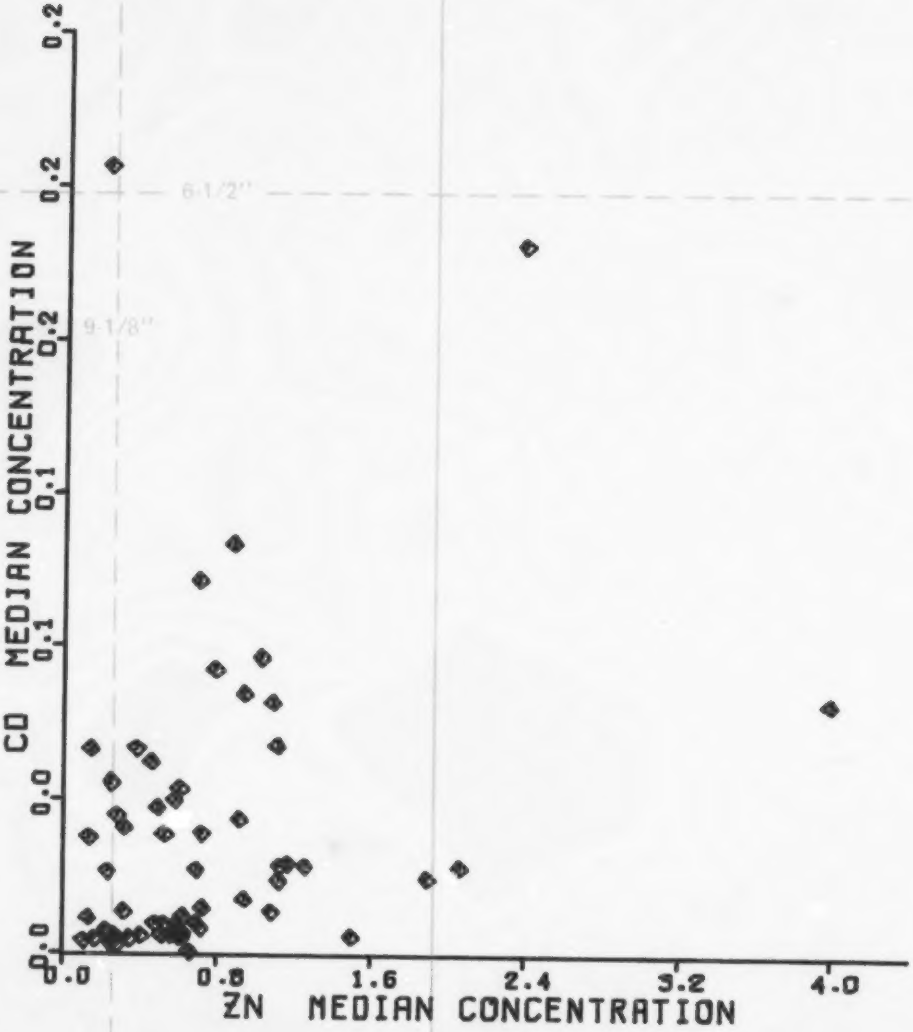

Figure G-4.

BEGIN LAST LINE OF TEXT
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3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

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TOP OF IMAGE AREA
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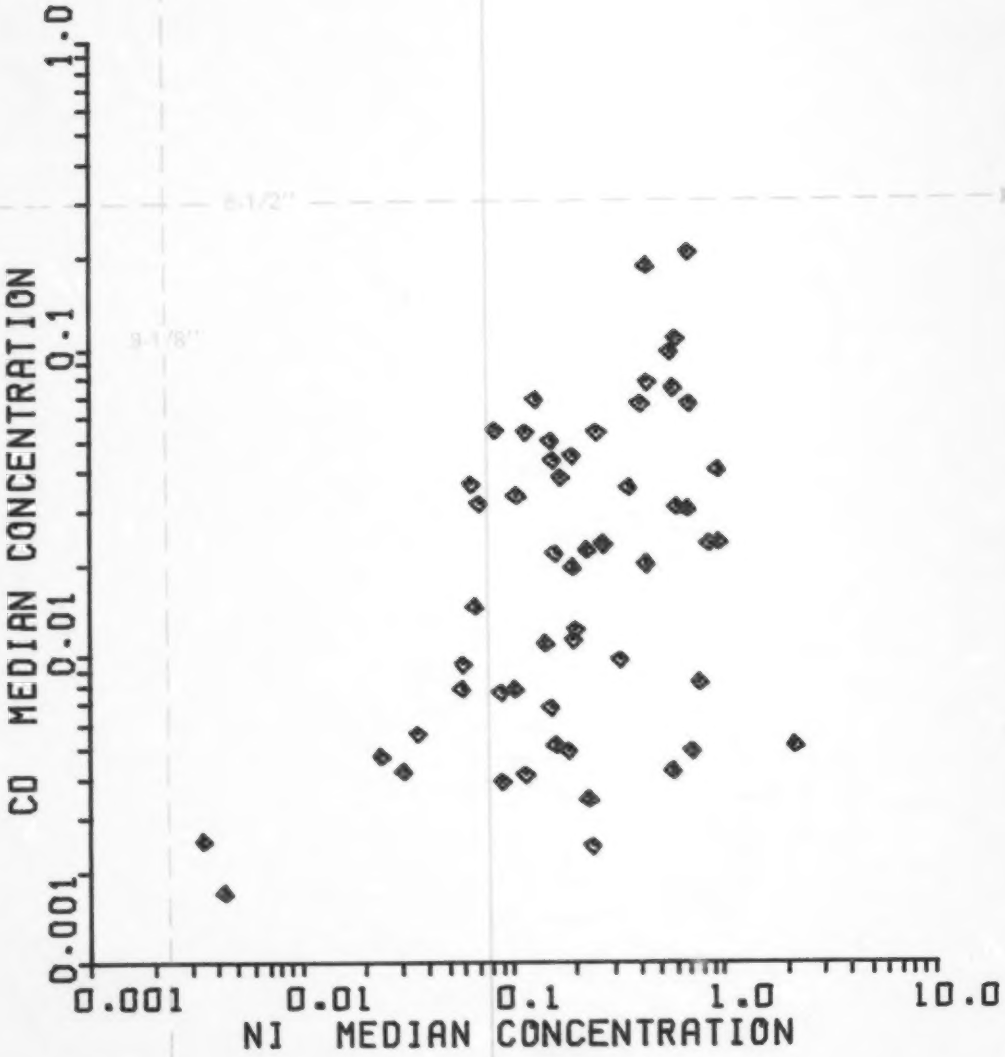

Figure G-5.

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3/8"
PAGE NUMBER

EPA-287 (Cin.)
(4-75)

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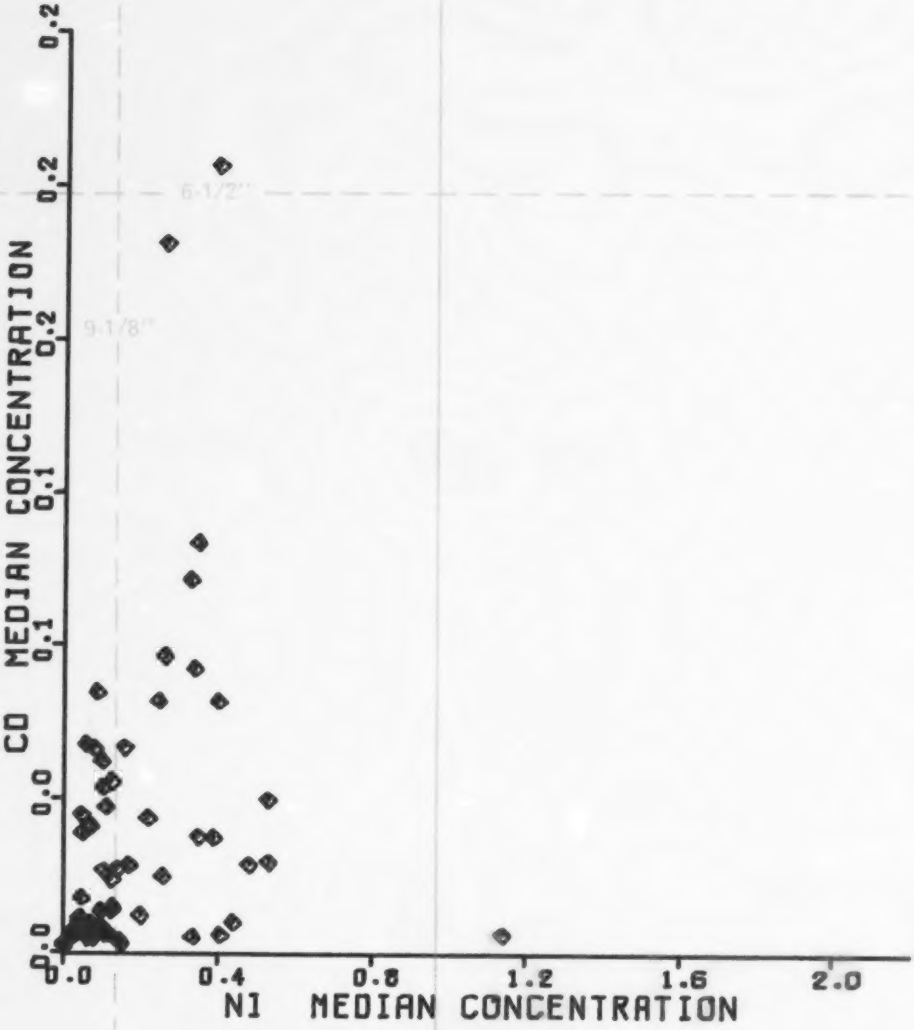

Figure G-6.

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BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

3/8"

PAGE NUMBER

EPA-287 (Cin.)
(4-76)

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TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
9-1/8"

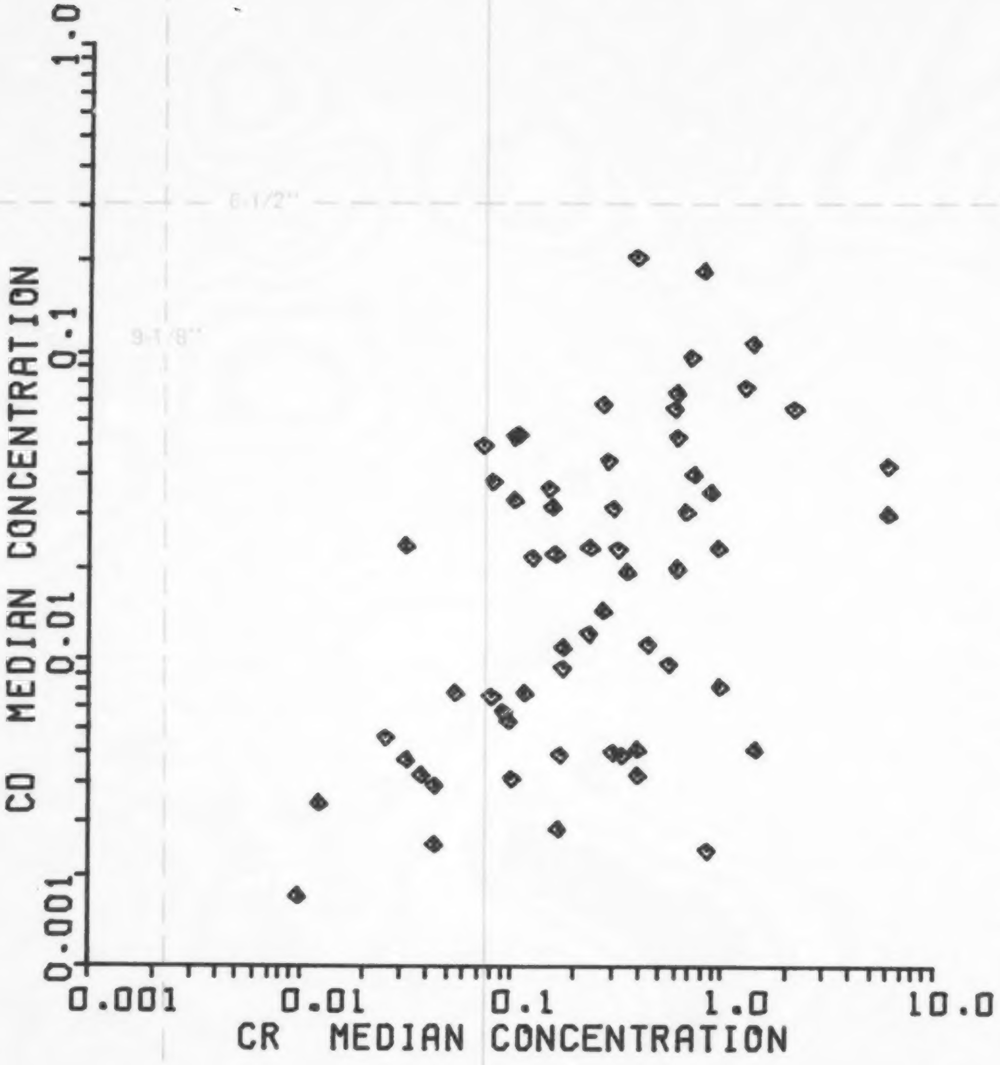

Figure G-7.

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3/8"

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
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TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2''
9-1/8''

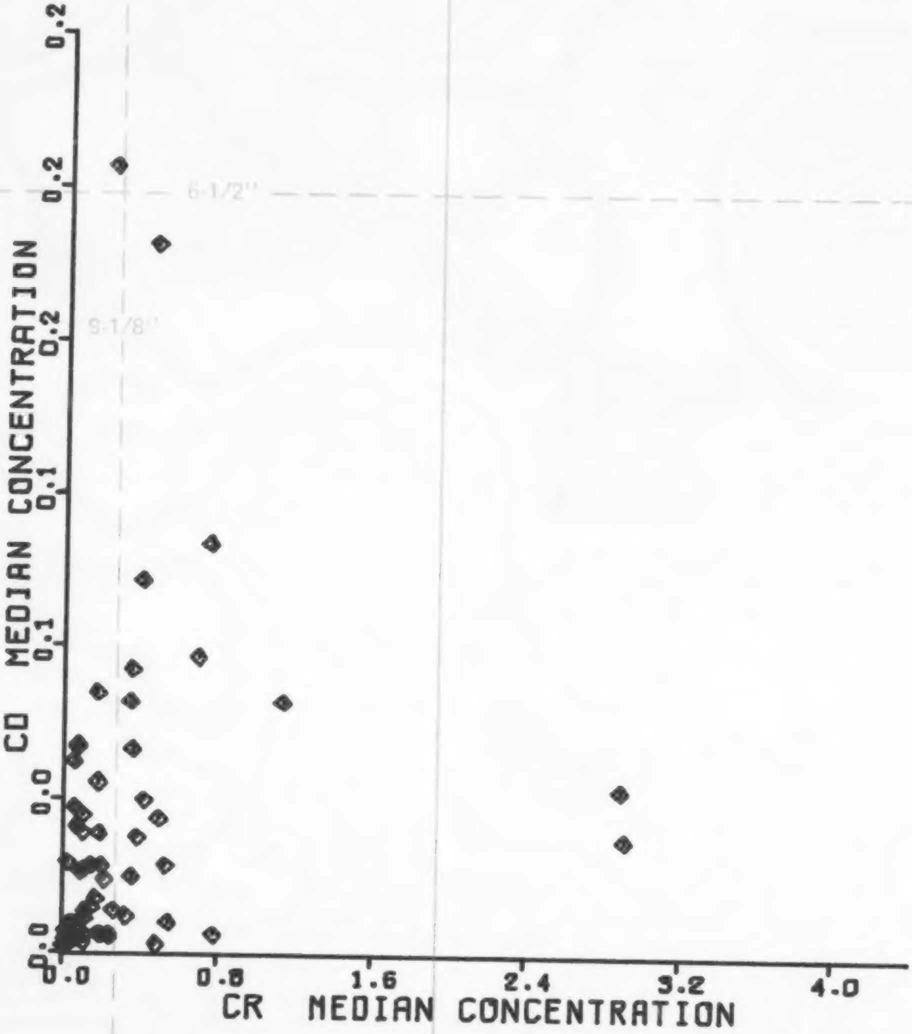

Figure G-8.

BEGIN LAST LINE OF TEXT
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3/8''

PAGE NUMBER
EPA-287 (Cin.)
(4-76)